Practical Wireless Telegraphy

A COMPLETE TEXT BOOK *for* STUDENTS *of* RADIO COMMUNICATION

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Fully Illustrated

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circuits varies as the capacity of the coupling condensers. It is claimed this circuit possesses the advantage that a fixed degree of coupling between the primary and secondary windings can be held while the wave length adjustment of the antenna and local detector circuits is being varied throughout the range of the tuner. It is probable, however, that this statement requires qualification.

In general the student will note from the foregoing that in any complete wireless telegraph system four circuits must be adjusted to or tuned to the same frequency of oscillation in order that communication may be established, as follows: At the transmitting station the closed and open oscillation circuits are adjusted for resonance. At the receiving station the receiving aerial circuit is adjusted to the frequency of the oscillations of the transmitter and the local or secondary circuit adjusted to resonance with the receiving aerial circuit; and for maximum response, the receiving detector must be adjusted to its maximum state of sensitiveness.

129. The Carborundum Detector and Tuning Circuits.—The most widely used of all detectors is the *carborundum crystal rectifier,* the tuning circuits for which are shown in Fig. 153a, b, c. These diagrams indicate as well the apparatus included in a modern receiving set. In addition two modified circuits showing the connection of the potentiometer in various modern tuners, are presented. Before proceeding with an explanation of the circuits of Fig. 153a, the function of the *potentiometer* will be explained.

The application of a weak battery current to the carborundum crystal and head telephone circuit has been found to have a marked effect on the intensity of the incoming signals, but the strength of the current must be carefully and closely regulated and must be passed through the crystal in a definite direction to secure the maximum response. Ignoring for the moment an explanation of the function of the local current in a radio receiver, the reader should note the diagram, Fig. 154, showing the connections of the potentiometer to a local battery.

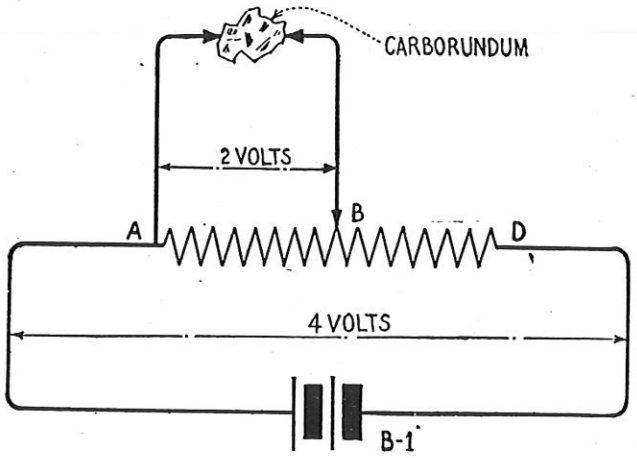


Fig. 154—Connections of Potentiometer for Crystal Detector.

A resistance coil A, D, is connected to the terminals of a 2 or 4 volt battery B-1. The crystal has the variable connection B which is generally a sliding contact. According to the law of divided circuits, *the maximum E. M. F. is maintained across the crystal when B is shifted to the end D, but in the direction opposite or towards A, the E. M. F. gradually reduces to zero.*

In the circuit originally adopted for the carborundum crystal, the potentiometer and detector were connected as in Fig. 153-a, but the modified circuits of Fig. 153-b and Fig. 153-c are also in use. In Fig. 153-b the telephone and potentiometer are *shunted* across the stopping condenser C-3 but in Fig. 153-c the potentiometer is connected in series with the crystal rectifier. Since the resistance of the crystal exceeds that of the potentiometer by several thousand ohms, the resistance of the latter has little effect on the strength of the incoming signal. Although practically equal results are obtained with either connection, the circuit of Fig. 153-b is pointed out by some investigators to be the one which gives the maximum response.

130. Adjustment of the Inductively Coupled Tuner.—During the reception of wireless telegraph signals the inductive receiving tuner may be adjusted to resonance with the sending station in the following manner:

If the *secondary circuit is calibrated* in wave lengths corresponding to various positions

the *secondary circuit may be set directly to the wave length of the incoming signal, taking care to select large values of inductance and small values of secondary capacity for any particular wave. The secondary winding should then be placed in partial inductive relation to the primary winding, followed by varying the capacity and inductance of the antenna circuit until response is obtained.* This is to be followed by adjusting the sliding contact on the potentiometer and trying new points on the crystal rectifier until the loudest signals are obtained in the head telephone.

Because the capacity and inductance of ships' aerials differ considerably it is evident that *a given primary winding will afford different wave length adjustments with different aerials,* consequently, the primary inductance changing switch cannot be calibrated directly in wave lengths previous to installation. But after the receiver is installed, the primary and secondary circuits both can be readily calibrated by comparison with a wavemeter and the adjustment for any particular wave length quickly duplicated whenever required.

In event that a receiving tuner is *not* calibrated, the receiver can be tuned to a given transmitter in the following manner:

(1) Set the secondary circuit approximately to the required wave length using large values of inductance and small values of capacity;
(2) Place the secondary inductance in close inductive relation to the primary inductance;
(3) Add inductance in the antenna circuit until response is obtained in the head telephones;
(4) Adjust detector to maximum degree of sensibility by potentiometer;
(5) Then reduce coupling between primary and secondary windings;
(6) Try new values of inductance and secondary condenser, also new values in the aerial circuit;
(7) Adjust in this manner for maximum strength of signals or until interference is eliminated.

(a) *Theory of adjustment.* Part of the energy of the oscillations induced in the receiver aerial *is lost by the resistance of the antenna conductors, part by re-radiation of the energy in the form of a wave motion and the remainder through transference to the local detector circuit. The energy imparted to the detector circuit is useful energy* because it produces the response in the head telephone, but the energy extracted in this manner also has a marked effect on the *tuning qualities* of the receiving antenna, which must be taken into account.

This may be explained as follows: If the secondary circuit is coupled loosely to the primary circuit, small amounts of energy will be extracted from the antenna oscillations; hence, the antenna will oscillate with greater persistence and will only respond with freedom to electric waves, the frequency of which coincides with its natural frequency of oscillation. On the other hand, if the primary and secondary circuits are coupled closely, a greater amount of energy will be extracted from the incoming oscillations and they will therefore be damped out more rapidly than under conditions of loose coupling. The receiving aerial will, under these conditions, respond to waves, the frequency of which may be somewhat greater or less than the natural frequency of the aerial circuit.

Thus it is seen that if the two circuits are closely coupled, the receiver circuits will tune "broadly" or if coupled loosely, the circuits will tune "sharply," that is to say, when the receiving transformer coils are loosely coupled, a small change of inductance or capacity will eliminate the signals of a given station, but when the receiver is "tightly" coupled, a much larger change of inductance or capacity will be required to eliminate the signals. This can be stated in another way by saying that the change of coupling between the primary and secondary circuits alters the effective resistance of the antenna and, therefore, has direct influence on the damping of the antenna oscillations.

It has been shown by several investigators that maximum response is obtained in a receiving apparatus so adjusted that the resistance of the primary and secondary circuits are equal and since the effective resistance of any receiving system varies widely according to the design of the aerial, the earth plate resistance and the type of receiving apparatus, it is clear that *some particular degree of coupling of the tuner will give the maximum response in the head telephone.*

The *two circuit receiver* with *inductive coupling* permits the receiving operator to eliminate the signals from interfering stations; in fact by judicious adjustment (of the coupling) signals of the same wave length can be eliminated provided they have different

secondary circuits to be loosely coupled and conversely a highly damped wave requires the receiver circuits to be closely coupled.

The antenna circuit at any receiving station can be made to tune more sharply by connecting a variable condenser in series and adding inductance until the wave length adjustment for resonance is obtained. This decreases the natural decrement of the receiving aerial but generally results in decrease of the strength of signals but the loss of signal strength is more than compensated for by the degree of selectivity obtained.

The *sharpest tuning* or the highest degree of selectivity is obtained in the local detector circuit when the variable condenser in shunt to the secondary winding is worked at small values of capacity with correspondingly large values of inductance for a given wave length; but if loose coupling is employed greater values of capacity and lesser values of inductance may increase the selectivity.

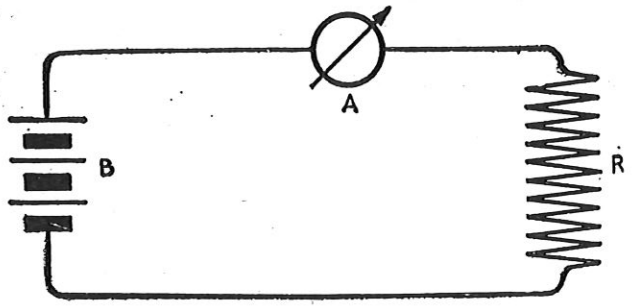


Fig. 154a—Circuit for Determining Volt-ampere Characteristic of a Given Conductor.

As will be seen from the foregoing explanations, interference can be prevented at the receiving station: (1) *by employing loose coupling between the primary and secondary windings;* (2) *by inserting a condenser in the antenna circuit and adding inductance until resonance is secured for a given wave length.*

Irrespective of the selectivity obtained by radio-frequency tuning, spark transmitters having *different spark notes* tend to prevent interference. By skill obtained through practice, the receiving operator can pick out a spark note of particular pitch and translate the signals through the interference of one or more stations, the more so if the spark note of the station desired has a distinctive pitch. Occasionally interfering stations can be tuned out by *detuning* the closed and open circuits, but signals will only be received in this way when the receiving station is situated near to the transmitting station.

131. The Action of the Carborundum Crystal.—Before proceeding with an explanation of various detectors and the circuit best adapted to their operation, we will briefly consider a generally accepted explanation of the operation of the carborundum detector and the function of the local battery current during the reception of radio signals.

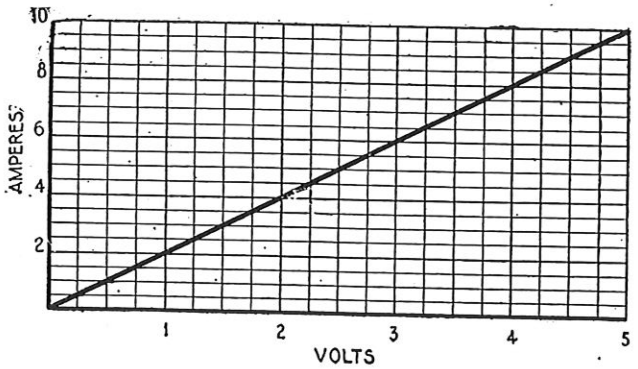


Fig. 155—Characteristic Curve of Ordinary Resistance.

The student is now aware that if we have a circuit such as shown in Fig. 154a, consisting of a variable source of direct current B to which is connected a resistance R and an ammeter A in series and if the voltage at B is progressively increased, the flow of current as indicated by the ammeter, increases in the direct ratio in accordance with Ohm's law. Furthermore, if we plot the results of this experiment in the form of a graph on cross section paper, as in Fig. 155, we find that a line drawn common to all co-ordinate points located in accordance with the data, will be straight and uniform. *Let it be noted from this curve that if the voltage be doubled, the current is doubled and so on.*

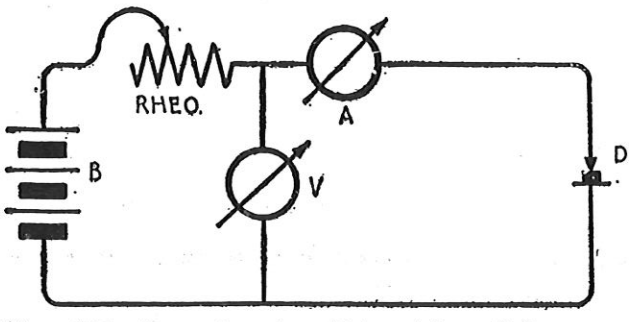


Fig. 156—Apparatus for Determining Volt-ampere

Now if we substitute for the resistance R a crystal of carborundum D as in Fig. 156, we find first, that the current in one direction with a given impressed voltage is much greater than when passed through the crystal in the opposite direction and second that if the current flows in the

direction of best conductivity and the voltage again progressively increased, the results do not accord with Ohm's law as the curve, Fig. 157, clearly indicates, e. g., the current is not proportional to the voltage. It will be seen that in the first part of the curve a progressive increase of voltage does not cause much increase in current, but after a certain critical voltage is passed the current increases more rapidly. The resistance of the crystal is, therefore, not steady. A curve of this type is said to have a *rising characteristic.*

We may now assume this curve to apply to the detector circuit of Fig. 153a and that signals are being received from a given station. Let the E. M. F. of the battery be three volts. From the curve, Fig. 157, we note that the corresponding current is 6 microamperes. Now let the alternating current of radio-frequency (the incoming signal) have for purposes of illustration a potential of one volt and let it be superposed upon the battery current flowing through the crystal. Then in one direction 1 volt will be added to 3 volts and from the curve, the current corresponding to 4 volts is 16 microamperes. But when the alternating current flows in the opposite direction it opposes the local battery and the resultant E. M. F. is 2 volts. Reading from the curve we obtain a current value of 2.5 microamperes.

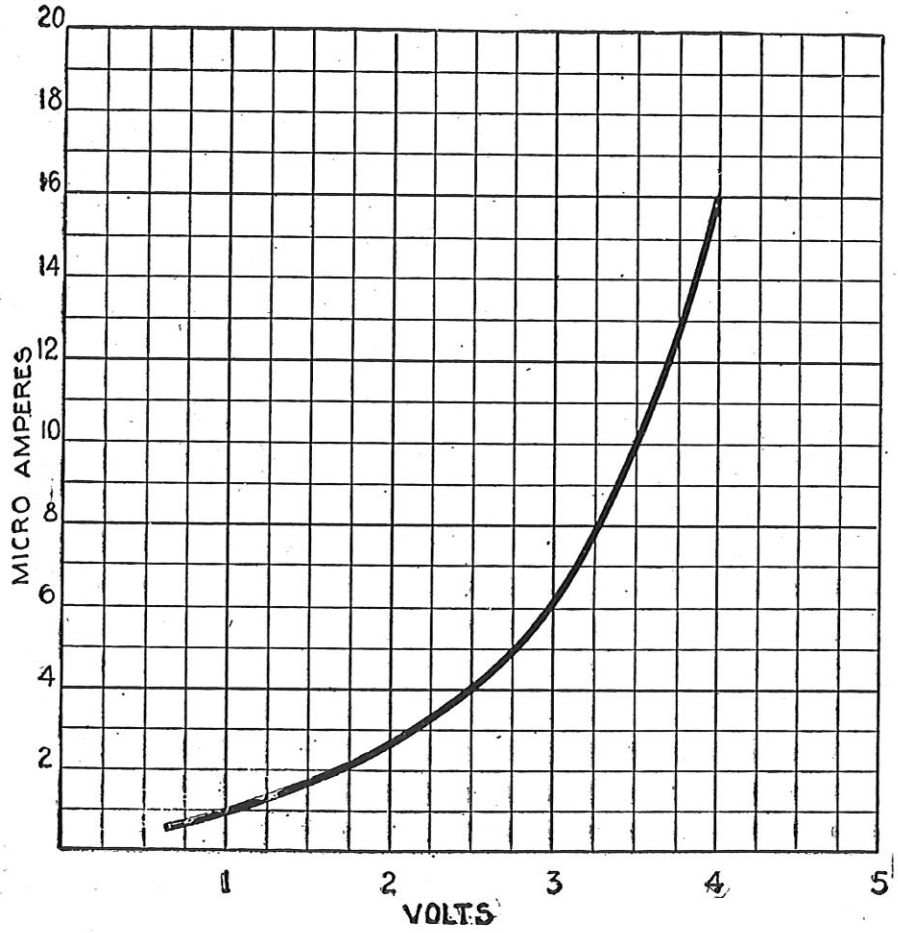


Fig. 157—Characteristic Curve of Carborundum Rectifier.

It will thus be seen under the influence of the impressed alternating E. M. F. that the current in the local battery circuit varies between 2.5 and 16 microamperes, but the sound produced by the head telephone, as will be explained, is proportional to the difference between the *normal current* flowing through the crystal and the *average value of current* flowing when an external oscillating voltage is applied. This, perhaps, can be more clearly explained by means of the curves shown in Fig. 157a, where the effect of superposing the antenna oscillations on the local battery current over the duration of a single train of incoming oscillations is shown.

As shown in Fig. 157, the normal current flowing through the head telephone, when no oscillating voltage is applied, is 6 microamperes (the voltage of the battery being 3 volts), but when an oscillating current of 1 volt is added on that of the local battery, the maximum amplitude of the initial oscillation (Fig. 157a) in the wave train is 16 microamperes, and, of course, successive maxima will be of lesser amplitude according to the decay of the wave train (as shown by the series of decaying maxima). We see also that the successive reductions of the normal battery current (shown below the line A, B) are relatively small because, as shown in Fig. 157, for all voltages less than 3 volts the flow of current (in microamperes) through the local circuit is relatively weak. The result of this is seen to be a series of positive maxima of gradually decreasing amplitude to which the telephone diaphragm cannot respond individually but which produce an *average effect* in the receiver. The average current in the case of Fig. 157a may be considered for mere illustration to be 9 microamperes and the difference between the normal current 6 micro-

which produces audible sound in the receiving telephone. We may state the foregoing in another way by saying that the added voltage due to the oscillating E. M. F. being im-

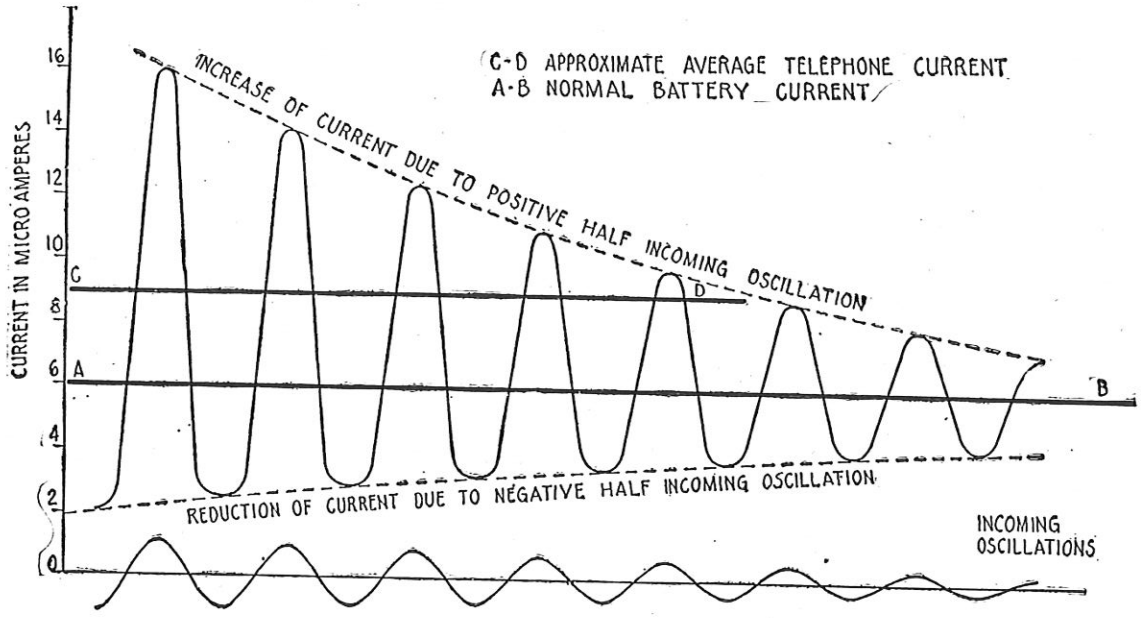
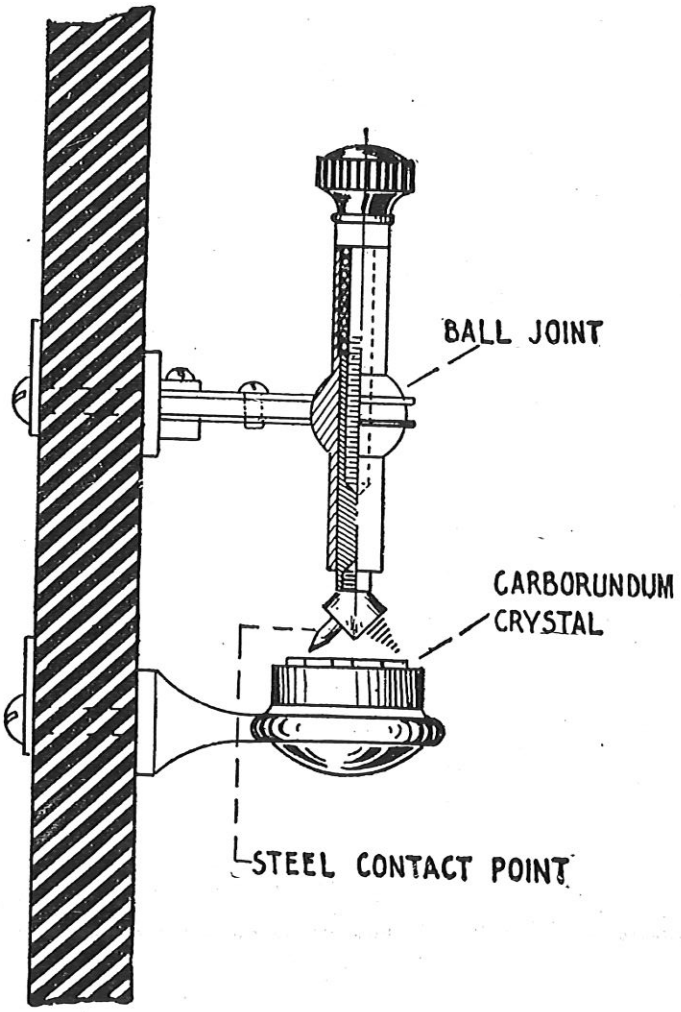


Fig. 157a.—Curves Showing the Fluctuations of the Local Battery Current flowing through the Carborundum Rectifier during the Reception of Signals.

pressed upon the crystal is greater than the subtracted voltage and that the final effect of this is an increase of current through the head telephone circuit over the duration of one wave train.

From the foregoing explanation it is apparent that when an operator at a given receiving station adjusts the position of the sliding contact on the potentiometer for maximum signals, *he adjusts the flow of current through the crystal and head telephone to correspond to the critical point on the characteristic curve,* or, in other words, to that point on the curve where the superposition of a slight antenna E. M. F. upon the local E. M. F. causes a relatively large change in the strength of the local battery current. And it also follows that the steeper the characteristic curve of a given crystal, the greater will be the change of current for a given impressed alternating voltage. In other words, the crystal with a steep curve will give the loudest signals and is said to be *"more sensitive"* to incoming oscillations.



132. Adjustment of Crystal Detectors.—No specific rule for locating the sensitive spot on a crystal rectifier can be laid down; in fact, the pressure and position of the opposing contact for maximum signals can only

borundum crystals as a whole require greater pressure at the opposing contact than crystals of galena, silicon, etc., although certain crystals under observation have required exceedingly light contact pressure. *With all crystals employing a local battery, it is important that the local current flow in a certain direction and that its strength be carefully regulated.* This means in practice that either the connections to the battery must be reversed, or the crystal must be turned about in the holder and left at the position in which the loudest signals are obtained from a given sending station. The potentiometer, of course, must be adjusted simultaneously.

The circuit of Fig. 153-b is suitable for the *zincite-bornite detector* provided a fixed resistance of about 2,000 ohms is connected in series with the battery B-1 and the potentiometer P-1. Certain crystals of this combination respond better with a local battery while others do not require it, but with practically any crystal it aids at least in obtaining the sensitive adjustment to employ a local battery, e. g., the sensitive spot can be more quickly located.

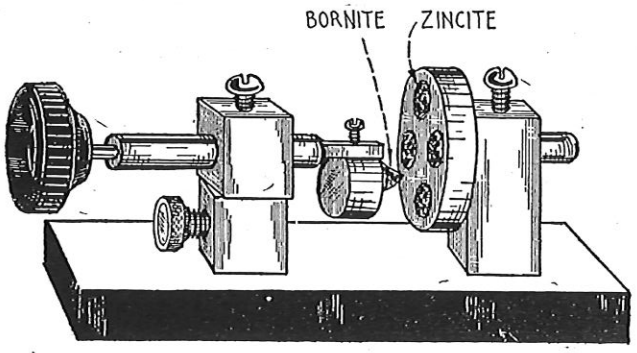


Fig. 159—The Zincite Bornite Detector.

If the test buzzer to be described further on is employed, a crystal can be adjusted to sensitiveness whether or not the distant transmitter is in operation.

133. Detector Holders.—Two types of crystal holders appear in figs. 158 and 159. The first is suitable for the carborundum crystal which is mounted in a small brass cup with some form of soft metal such as Wood's metal. A small point, such as a steel phonograph needle, is mounted on the movable arm and makes contact with the crystal. During adjustment this point is *"jabbed in"* at various points on the crystal until a sensitive spot is located.

A *detector holder* suitable for the zincite-bornite detector is shown in Fig. 159. The large cup is filled with 5 or 6 *zincite* crystals while the opposite cup carries a crystal of *bornite*. The cup is fastened to the end of the arm with the universal joint. The crystal of bornite may thus be placed in contact with the surface of any of the zincite crystals being shifted from one to the other until the adjustment for maximum strength of signals is found.

A variety of crystals holders have been designed for crystals of *galena, silicon, cerusite,* etc. One type appears in Fig. 160, where the crystal is held in a small cup by three screws. A light wire contact mounted on the movable arm bears with slight pressure on the surface of the crystal.

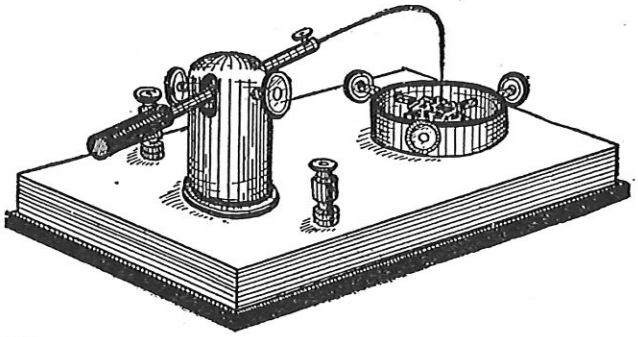


Fig. 160—Detector Holder for Galena and Silicon Crystals.

134. Classification of the Receiving Detectors.—The receiving detectors of wireless telegraphy differ greatly both in point of mechanical construction and mode of operation, and, in addition, they possess widely varying degrees of sensitiveness. Certain types, for instance, are *highly sensitive* to electrical oscillations but are difficult to keep in permanent adjustment; others are *less sensitive* but possess *marked degrees of stability.* Still others are in the nature of a compromise and may occupy approximately a position midway between the two extremes.

Some receiving detectors rely upon the *principal of rectification* (as we have already shown) and will convert an *alternating current of radio-frequency to a uni-directional current;* others have the property of rectification combined with the *ability to vary a local source of battery current* in a manner much similar to the working of an ordinary telegraph relay. The operation of certain other detec-

upon the ability of these oscillations to cause certain *granulated metals to cohere.*

Perhaps the most highly developed of all receiving detectors are the *vacuum tube rectifiers* which are extremely sensitive and possess the important property of amplifying the signals when connected in cascade. Certain types of vacuum amplifiers will remain in a sensitive state of adjustment over an indefinite period or throughout their length of life.

It should be kept in mind that the most sensitive receiving detector is not always the one most convenient or the most practical for commercial use. For instance, extremely sensitive amplifying detectors may require intricate apparatus, having so many points of adjustment that its manipulation may call for the services of a highly skilled engineer and further the circuits may be of such a type that the apparatus cannot be quickly changed from one wave length to another. In event of the latter, the tuner would be of little value for marine service which requires the receiver to be one capable of quick adjustment to land stations operating at various wave lengths. Furthermore, extremely sensitive detectors bring in a certain amount of interference from far distant stations which would not be heard on less sensitive detectors.

The most practical detector for commercial working is one that combines a fair degree of efficiency with ruggedness and stability of adjustment, and so far among the crystal detectors none has, in this respect, excelled the carborundum rectifier. The Marconi magnetic detector is universally recognized as being the most stable and "foolproof" of all receivers but it lacks sensitiveness on the shorter waves. The vacuum valve detectors, on the other hand, are considered to be the most sensitive among commercial receivers, but they possess the disadvantage of requiring complicated circuits for best results.

To impress upon the reader's mind the *utility* of the various types of receiving detectors, we may classify them under five general headings. Under the first heading we may name the *detectors which require no local battery* and under the second heading, *those detectors* in which the response in the telephone depends upon the *application of a local battery current* as well as upon the current of the incoming oscillations.* Certain detectors may be classified under both headings because they may function to some extent with or without a local battery.

In addition we may note under a third heading the detectors considered as *rectifiers of radio-frequent* currents and in a fourth and fifth headings, those suitable for *response to either damped or undamped oscillations* respectively. It is to be noted that a few types come under all headings.

Detectors Functioning Without Local Battery.	**Galena—Silicon—Zincite Bornite—Carborundum (satisfactory for short distance receiving)—Fleming Valve (filament battery only).**
Detectors which depend upon the combined effects of received energy and local battery current.	**Carborundum—Zincite Bornite (sometimes used with local battery)—Fleming Valve (with local battery)—Three Element Valve—Silicon.**
Detectors having the Property of Rectification.	**Galena — Silicon — Carborundum — Cerusite—Zincite-Bornite—Fleming Valve—Three Element Valve—Electrolytic.**
Detectors of Damped Oscillations.	**Galena — Silicon — Zincite Bornite — Carborundum —Fleming Valve—Three Element Valve—Marconi Magnetic—(Tikker, Tone Wheel and Heterodyne system will give some response from spark transmitters, but are not satisfactory for such reception).**
Detectors of Undamped Oscillation.	**Tikker—Tone Wheel—Heterodyne Receiver—Vacuum Valve Oscillator.**

135. Fleming Valve Detector and Tuning Circuits.—A receiving detector of notable merit is the Fleming oscillation valve the action of which is primarily

* We should be careful to distinguish between oscillation detectors requiring a "local battery" and requiring a local "source of energy." For example, the Tikker, the Tone Wheel and the Marconi Magnetic detectors require a local driving force, which in reality take the place of the local battery; also the

based on the emission of *electrons* from highly heated metals in vacua. In its commercial form it consists of a highly exhausted glass bulb, Fig. 161, containing a 4 or 12 volt lamp *filament, F, of carbon, platinum or tungsten surrounded by a metal plate or cylinder P-2 of copper, nickel, etc.,* from which a connection is extended to the outside of the bulb.

When the filament is brought to a state of incandescence by a battery B, negative electricity can pass from the filament to the plate, but not in the opposite direction, hence when the terminals of the closed or secondary circuit of a receiving tuner are connected to the negative side of the filament and to the plate of the valve, the alternating current of radio-frequency flowing in the receiver circuits will be converted into a uni-directional current which may affect a head telephone or other recording instrument. More clearly, the oscillations flowing in the receiver circuits during the time of a complete group will be rectified by the valve placing a charge in the condenser C-2 (Fig. 161), which afterwards discharges through the head telephone, creating a single sound for each group.

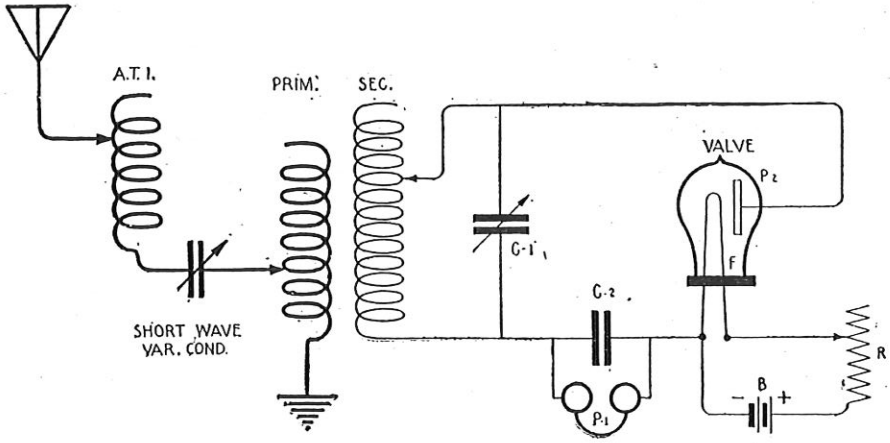


Fig. 161—Fleming Oscillation Valve and Tuning Circuits.

The *adjustment of the Fleming oscillation valve* is extremely simple and the stability of the device particularly marked, in fact it is only necessary to adjust the incandescence of the filament until loud response from a given station is obtained in the head telephones. This is accomplished by the rheostat R which normally is of 10 or 15 ohms resistance.

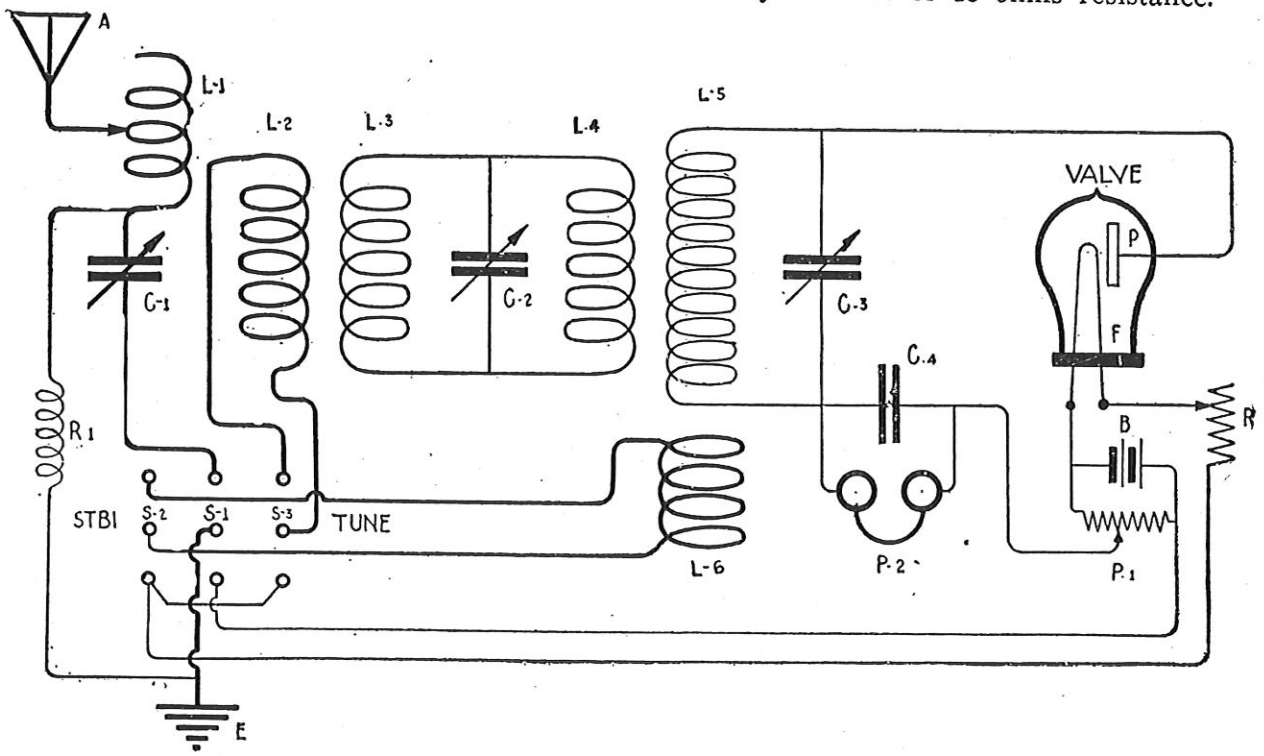


Fig. 162—Fundamental Circuit of Marconi Valve Tuner.

The Fleming valve gives signals of greatest strength when the secondary circuit is designed for a minimum value of shunt capacity and a maximum value of inductance for a given wave length or frequency, hence the secondary condenser is always worked at low values of capacity.

and the plate. Like the carborundum detector, the Fleming valve has a rising characteristic and when an E. M. F. is applied to the space between the plate and the filament the current may be adjusted to the critical point on the characteristic curve so that the addition of a slight antenna voltage causes a large increase of the local battery current flowing through the head telephones.

A satisfactory diagram appears in Fig. 162 wherein a potentiometer P-1 is shunted across the filament battery and a portion of the current flows through the head telephones and the detector. With this arrangement of circuits advantage is taken of the particular volt-ampere characteristic of the valve and a relay action due to a local source of energy is obtained. For the maximum strength of signals with this circuit it is necessary to adjust the position of the sliding contact on the potentiometer as well as the incandescence of the filament, until the desired results are obtained.

The diagram, Fig. 162, shows the fundamental circuit of the widely used *Marconi-Fleming valve receiver*. The *open circuit* comprises:

(1) The aerial tuning inductance L-1,
(2) The short wave condenser C-1,
(3) The primary winding L-2,
(4) The shunt impedance R-1,
(5) The change-over switch S-1, S-2, S-3.

The *intermediate circuit* comprises:

(1) The winding L-3 in inductive relation to L-2,
(2) The winding L-4 in inductive relation to L-5,
(3) The variable condenser C-2.

The *secondary circuit* comprises:

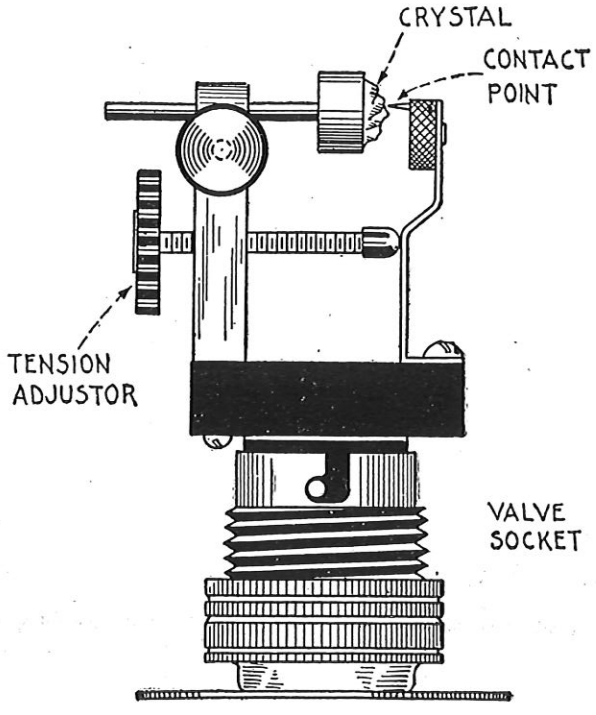
(1) The secondary winding L-5,
(2) The billi condenser C-3,
(3) The Fleming valve F, P,
(4) The battery B (or four volts generally),
(5) The 10 ohm rheostat R.
(6) The 400 ohm potentiometer P-1,
(7) The fixed condenser C-4,
(8) The head telephone P-2.

Inductances L-2, L-3, L-4, L-5, L-6 are of fixed value, but L-1 is variable through the medium of a multi-point switch.

When the D. T. three blade switch S-1 is thrown to the right, primary winding L-2 is connected in series with the *aerial circuit* which brings the *intermediate circuit* into use, but the switch, thrown in the opposite direction, disconnects L-2 and connects L-6 in series with the aerial. L-6 being wound tightly about the turns of L-5, the open and closed circuits are closely coupled. *This increases the damping of the receiving system* and makes the set responsive to waves of different length at one set of adjustments, but, of course, does not give the strength of signals that can be obtained by resonant adjustments.

The position of the switch corresponding to *"close coupling"* is marked "Stdbi," an abbreviation for the word "standby." The switch is placed in this position when a particular receiving station awaits a call from one of several sending stations which are not exactly tuned to the same wave length.

In the opposite position the changeover



of this connection, sharp resonant adjustments can be obtained. The wave length of the *intermediate circuit* is increased or decreased by the variable condenser C-2 only and similarly the wave length of the secondary or detector circuit, by the condenser C-3.

The coupling between the inductances of the intermediate circuit and inductively related coils is varied simultaneously by means of a shaft (and knob) upon which both coils, L-3 and L-4, are mounted.

The impedance coil R-1 prevents the accumulation of high voltages upon the dielectric of the variable condenser, which may be punctured in case the windings of the tuner should come in direct contact with the high voltage wires of the transmitting apparatus.

The American Marconi Company has developed a crystal holder to fit in the Fleming valve socket as shown in Fig. 163. The circuit for the crystal detector is practically identical with that of the oscillation valve with the exception that the lighting battery is connected to the potentiometer instead of to the lamp filament.

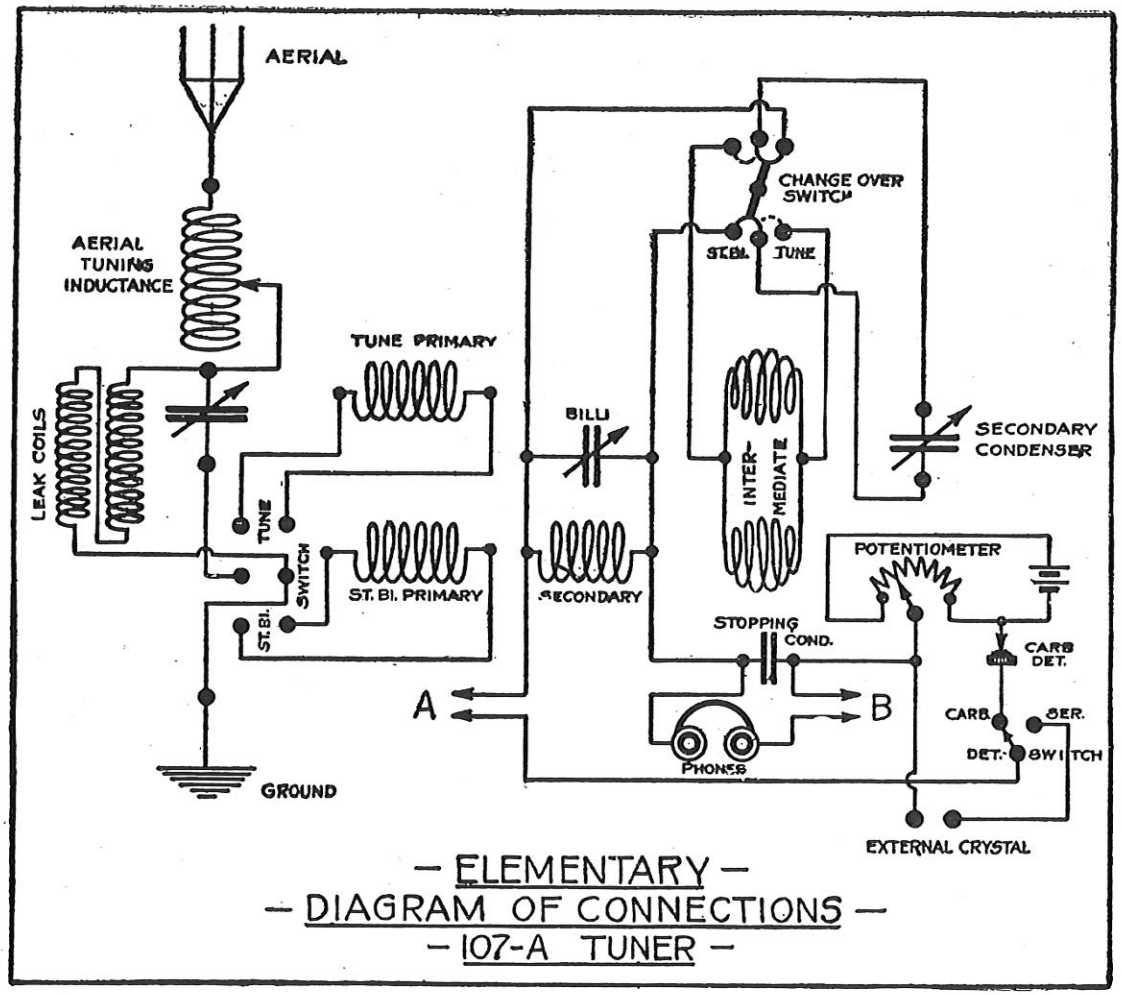


Fig. 164—Complete Circuits of Type 107a Tuner (American Marconi Company).

The valve tuner was original designed to be responsive to waves varying between 300 and 1,650 meters in length, but the circuit has been modified to respond to waves up to 2,500 meters, as in Fig. 164.

136. Marconi Type 107-a Tuner. (American Marconi Company).—The various connections and arrangements of circuits of the Marconi type 107-a tuner are shown in Figs. 165-a, 165-b and 165-c. The principal change over the ordinary valve circuit lies in the special six point double throw switch (marked *"change-over switch"*) which disconnects the condenser of large capacity (.01 microfarads) across the *intermediate circuit* and places it in shunt to the secondary winding and the *billi-condenser* (see Fig. 165-a). With the increased capacity of this condenser in shunt, the secondary circuit will respond to a wider range

For the reception of wave lengths exceeding 1,500 meters, the D. P. D. T. switch is thrown to the *"standby"* position and the intermediate circuit cut out. For wave lengths below 1,000 meters, either the *"standby"* or *"tune"* circuits can be employed at the discretion of the operator.

It is to be noted, although the 107-a tuner is designed for the carborundum detector, an extra set of posts is provided for an additional crystal such as

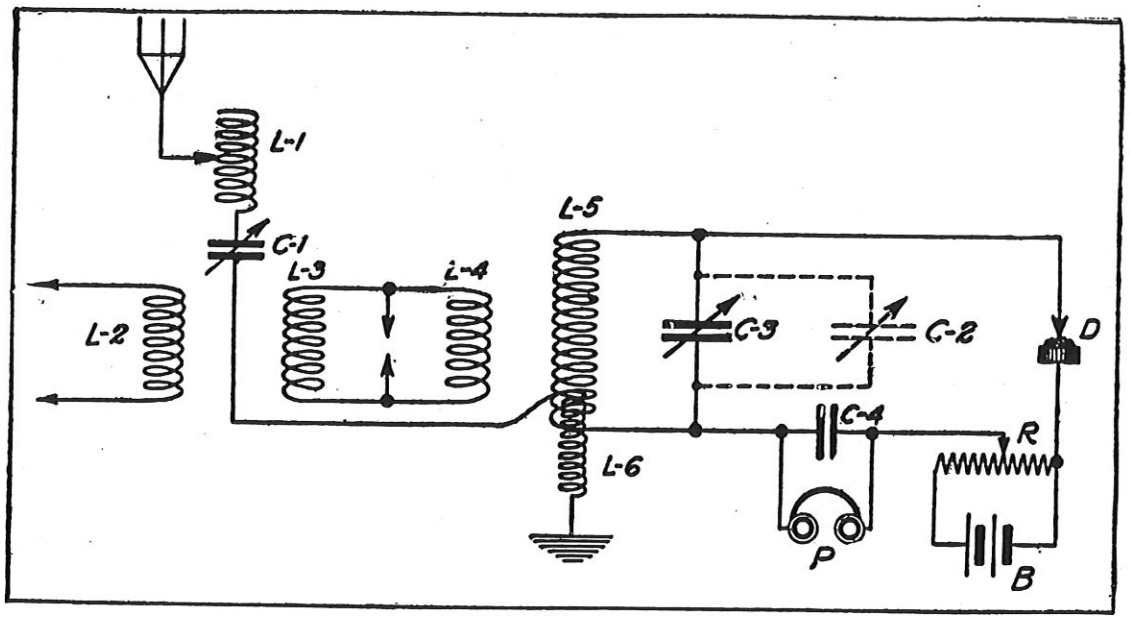


Fig. 165a—"Standby" Long Wave Adjustment of Marconi Type 107a Tuner.

cerusite. When the latter detector is employed, the potentiometer is out of the circuit. Observance next should be made of the binding posts from which wires are connected to the receiver circuits and to the contacts of an aerial change-over switch. The latter, when open, protect the detector and head telephones from the induced potentials of the local transmitter.

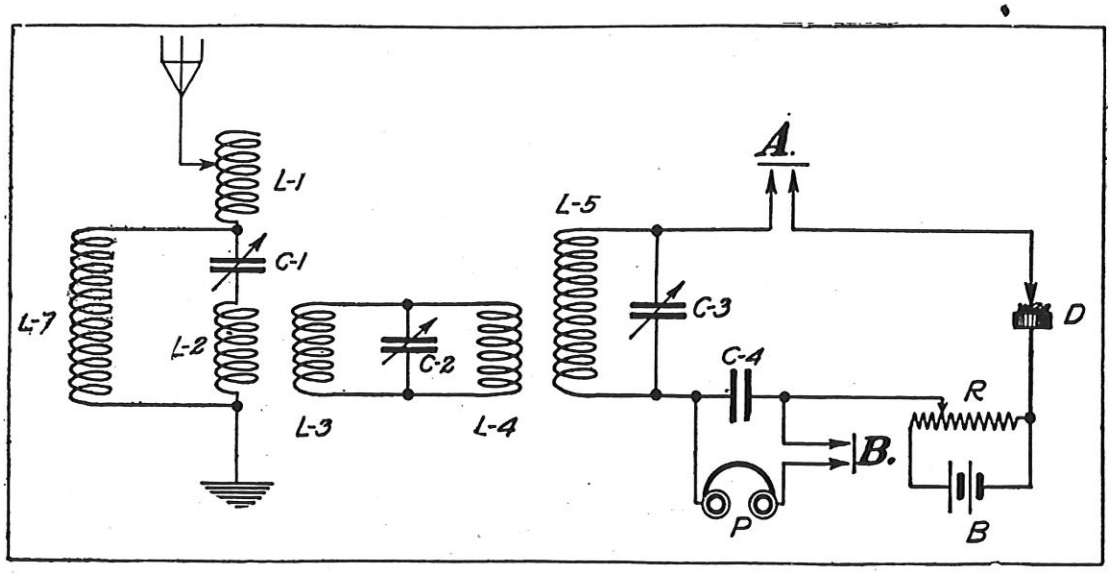
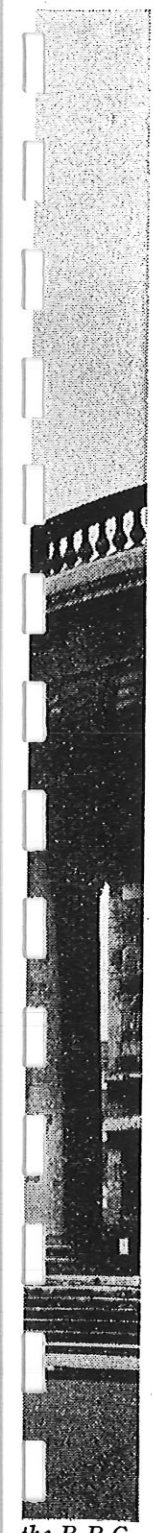


Fig. 165b—"Tune" Circuits of Type 107a Tuner.

In the diagram, Fig. 165-b, L-1 is the aerial tuning inductance, the value of which is altered by means of a multi-point switch mounted on the left hand front of the tuner.

C-1 is the short wave variable condenser connected in series with the aerial system. In the full scale position it short circuits itself and is thus cut out of the antenna circuit. This condenser is mounted on the left hand side on the top of the tuner.

L-2 is the primary winding of the receiving tuner and has a fixed value of inductance



the B.B.C.

THE OUTLINE OF WIRELESS

FOR THE MAN IN THE STREET

BY RALPH STRANGER

LONDON
GEORGE NEWNES, LIMITED
SOUTHAMPTON ST., STRAND, W.C.2

CHAPTER XII

DETECTION OF WIRELESS SIGNALS

§ 1

WHY HAVE A HIGH-FREQUENCY CURRENT?

In Chapter XI, *Selection of Wireless Signals,* I brought to the attention of my readers the first circuit of any wireless receiver—*the tuning circuit.* Thus we already know that once the electromagnetic wave reaches our receiving aerial, and the latter has been properly tuned to the frequency of the incoming wave, we shall have a high-frequency oscillating (alternating) current circulating in our aerial system, which will influence the remaining receiver circuits.

Let us consider a particular case when the tuning circuit is followed immediately either by a crystal detector or a valve detector. This means that the points A and B of the tuning circuit are connected directly across the detector (Figs. 435 and 436).

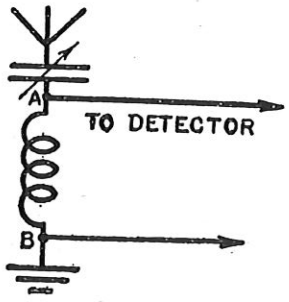


FIG. 435

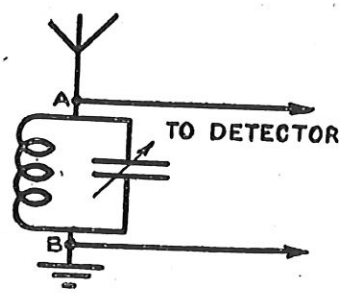


FIG. 436

Now, what is the detector circuit going to do with the high-frequency modulated current in the aerial?

The problem of the broadcasting station is to produce sounds in the studio, interpret these sounds in terms of electrical currents, with the help of the microphone, impress the microphonic currents upon the high-frequency carrier current already flowing in the aerial, and thus modulate it. The modulated high-frequency alternating current flowing in the transmitting aerial will result in disturbances in the ether, so that a train of modulated ether waves will start to leave this aerial in all directions. The

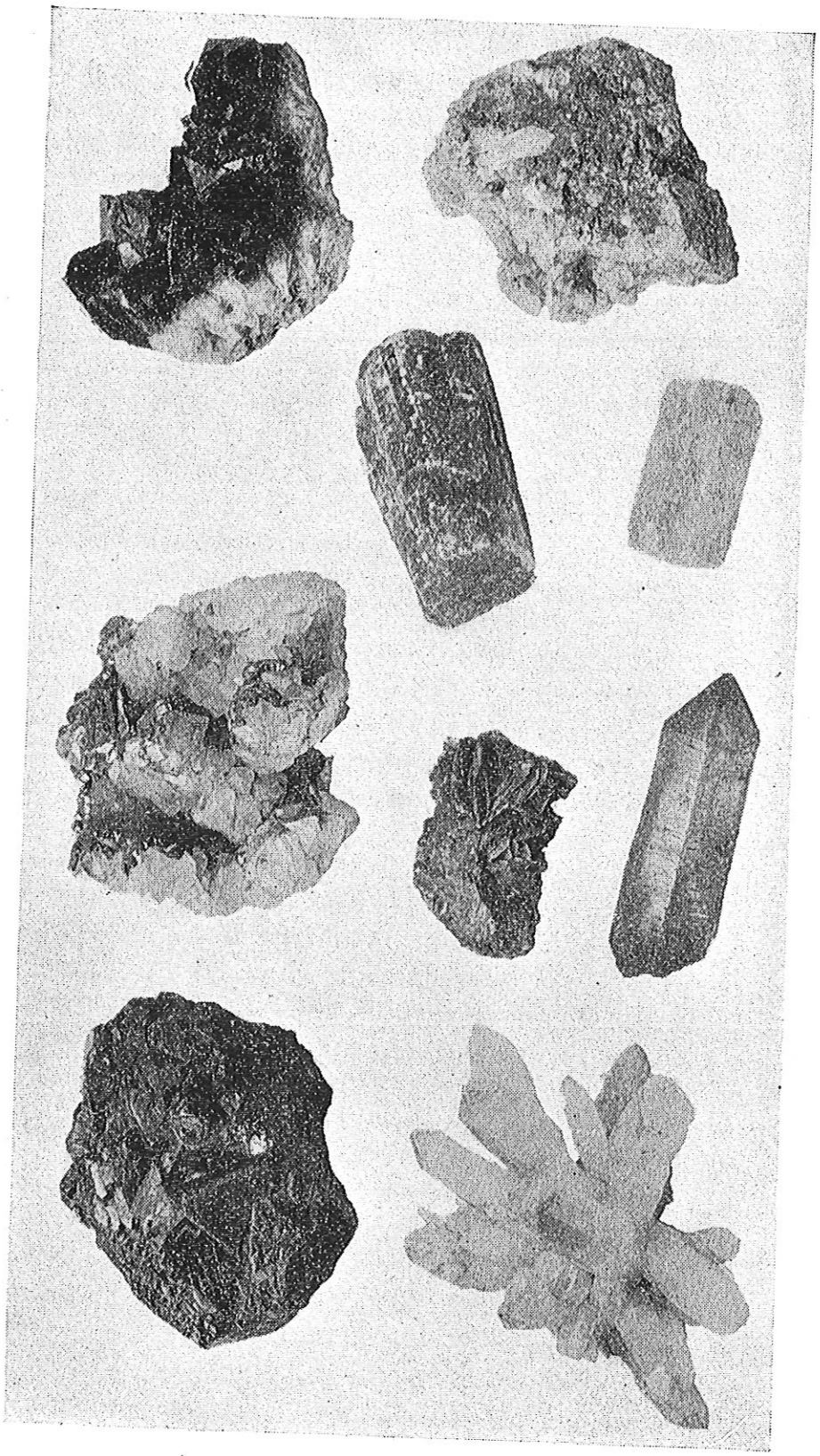
ether waves, on reaching the receiving aerials, will induce in each of them modulated high-frequency alternating currents, identical in character with those circulating in the transmitting aerial.

These induced high-frequency alternating currents will consist of two portions, or, let us say, two components, the high-frequency carrier current and the superimposed on it low-frequency, or microphonic current. It is the latter that bears the sound characteristics and is capable of actuating a telephone or a loud-speaker diaphragm so that the studio sounds are reproduced, more or less, exactly as they are emitted. The high-frequency current is useless in itself as far as the diaphragm of the telephone or a loud-speaker is concerned. Its variations are so rapid that no diaphragm could possibly follow them. It is the low-frequency component that matters to the receiver, and the work that the detector circuit has to perform is to separate the useful from the useless, i.e. to separate the low-frequency component of the current from the high-frequency one. Once this is done, a current is obtained which is varying in accordance with the variations of sound in the studio, and is capable of causing the telephone diaphragm to vibrate in precisely the same way in which the microphone diaphragm was vibrating.

You will say: "Why have a high-frequency current at all? Why cannot the transmitting station transmit low-frequency waves and thus induce in our aerials low-frequency currents corresponding to the frequency of sounds emitted in the studio, so that there is no need to separate anything?"

Well, we must use the high-frequency carrier current for the sake of economy. Just consider the following: the audible range of a human ear lies between 12 cycles per second and 30,000 cycles per second. This range varies slightly with the individual.

Let us assume that we have to transmit one note of a frequency of 3,000 cycles and another of 10,000 cycles. When these sounds are interpreted electrically, we would have to emit two waves, one after another, the first of 100,000 metres wave-length and the other of 30,000 metres. To be able to emit a wave of 100,000 metres wave-length or to receive the same one would require a



CRYSTALS

tremendous aerial, huge coils, and terrific condensers. Moreover, if one has to jump from 100,000 metres to 30,000 metres from instant to instant, one would meet difficulties which those who know a little about tuning will appreciate.

Transmitting on long wave-lengths would mean, apart from other difficulties, a very costly receiving equipment, so costly that no listener could afford it, unless he were a millionaire, or unless we had a very kind Chancellor of the Exchequer who would abolish all income-tax.

Well, what with the income-tax, and the cost of large aerials, coils and condensers, it is a much cheaper method, both from the point of view of the broadcasting authorities and the listeners, to have a high-frequency carrier current with the low-frequency current impressed upon it. After all, the detector circuit is perfectly capable of separating the two currents quite nicely, and is quite cheap. Thus, instead of transmitting on 100,000 or 30,000 metres, we have our transmitting stations working on a range of wave-lengths lying between 175 metres and 2,000 metres. Considering the present state of our pockets, it is just as well.

There are two kinds of detectors in use at the present moment: the *crystal detector* and the *valve detector*.

The crystal receiver represents a most inexpensive method of wireless reception, and it has also the additional advantage of almost perfect reproduction. I have yet to hear a valve set, moving-coil speaker or no moving-coil speaker, that would give as good results, from the quality point of view, as the crystal set. The trouble with the crystal sets is that they are not selective enough, and have a small range.

Although the modern listener may look down upon what many people would call an obsolete method of reception, there is more in the crystal set than meets the eye. I think that you will agree with me that Scots as a rule are a very intelligent people. Well, you would be surprised if you knew how popular the crystal receiver is beyond the border!

We know precious little about the nature of crystals as yet, and there is a tremendous amount of research to be done in this direction.

I would like some of my readers to whom science is a hobby, and who have plenty of spare time on their hands, to combine the studies of mineralogy, with a special emphasis on crystallography, with the study of crystal detectors. Having covered the theoretical field, get somehow or other as many different specimens of crystals as possible and try them out as detectors of wireless signals under varying conditions. A good deal of research has already been done in this direction, as you will see later, but there are a good many substances that have never been tried yet.

I propose to devote a good deal of space to crystals, and I do not think that I need apologise for it either, as this subject is highly important from the point of view of any wireless experimenter.

Now, let us see what sort of crystals can be used for the purpose of wireless detection.

§ 11

MINERAL CRYSTALS

All substances can be divided into two distinct classes. *amorphous* substances and *crystalline* substances. An amorphous substance appears as a lump of matter without any definite geometrical structure, unless it is shaped either by vagaries of nature or human hands. Crystalline substances, on the other hand, are fashioned out of a number of more or less perfect geometrical shapes, such as the cube, the pyramid, the triangular prism, etc. Some such crystalline masses are shown on page 549. A crystal may come into existence by gradual growth from a liquid, or may be left as a residue of evaporation of a chemical solution. This is how crystals were left embedded in various rocks and can be found amongst the more widely distributed ores.

The reason why crystalline substances exhibit such a regular pattern lies in that the atoms of the molecules of such substances are arranged by Nature in a perfectly orderly manner. Let us take as an example the crystal of ordinary table salt (NaCl). On examination it was found that salt crystals are built up of tiny cubes, of one-hundred-millionth of an inch side. It was also found that the atoms of sodium (Na) and chlorine (Cl) are arranged in such a way that they occupy the opposite corners of each cube, as shown in Fig. 437.

The reason for the permanency of such a structure was found in the fact that in a crystal of salt all the chlorine (Cl) atoms are negatively charged, while the sodium atoms (Na) are positively charged. If you turn to Chapter I, *Matter and Energy,* and read once more Section X, you will discover the reason for these electrical charges. This means that the crystal structure is being held together by electrical attraction between the atoms. If you bear this in mind, some of the electrical properties of crystals will become a little clearer to you.

It is interesting to note that the angles between the corresponding faces of all crystals of the same chemical substances are always the same. Not all crystals are symmetrical; in some cases the growth is accompanied

by distortion of some of the faces owing to external conditions. Crystals, in growing together, form complex regular bodies, such as twin pyramids, triple cubes, etc. Now and again foreign bodies are found inside crystals, and there may even be an internal cavity filled with a liquid or a gas.

The properties of crystals are highly interesting. Various crystals differ a good deal in hardness, the diamond being the hardest crystal known. As you probably know, both diamond and graphite are crystalline modi-

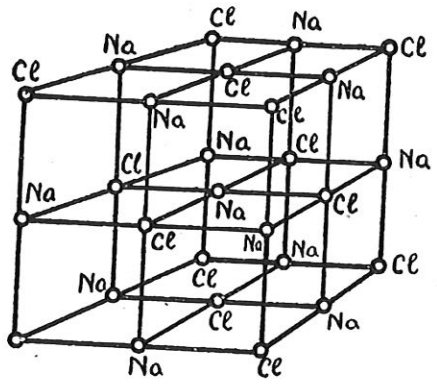


FIG. 437

fications of the same element, carbon. And yet, while diamond is one of the hardest substances, graphite is quite soft.

There are minerals, such as cyanite, which have faces of differing hardness. Crystals possess well-known optical properties, but as those are at the moment beyond the scope of our studies, we shall pass on to other properties which have a greater bearing on the subject. It is of interest, however, to note that the crystal of Iolite appears dark blue when viewed in one direction, and pale blue or pale yellow when viewed in one of the other two directions. It is also necessary to note that the optical properties of crystals vary a good deal with the variation of temperature.

From the point of view of thermal properties it was found that *crystals conduct heat at different rates in different directions.*

In the case of cubic crystals, with the increase in tem-

perature the expansion is the same in all directions, but this law, however, does not hold good for crystals of other shapes.

Crystals, in common with other substances, are either diamagnetic or paramagnetic (see Chapter IV, *Magnetism and Electro-Magnetism*), i.e. they are either repelled or attracted by a pole of a magnet. Magnetisation induced in crystals is different in different directions, with the exception of cubic crystals.

Now we come to a property of crystals which has a direct bearing on our subject: *The electrical conductivity of crystals varies with the direction of flow of electrons and bears the same relation to the symmetry of the crystal as the thermal conductivity.*

Conducting crystals are thermo-electric (see Chapter III, *Electronic Currents*, Section X). It is interesting to note that some crystals of the pyrites group are more positive thermo-electrically than antimony and others are more negative than bismuth. It is possible, therefore, to select a pair of crystals which will form a more powerful couple than antimony and bismuth.

Some crystals, when subjected to a difference of temperature, will develop a positive charge on one face and a negative charge on the opposite face. Needless to say that such crystals are non-conducting.

Another remarkable property is that when non-conducting crystals are subjected to a varying pressure, electrical charges are developed on the opposite faces. This may be the same effect as above, as during changes in temperature expansions and contractions are produced which result in varying pressures.

§ III

CRYSTAL DETECTORS

The detecting property of the crystal lies apparently in its varying conductivity of electrical currents in different directions. Thus a suitable crystal, while it will pass a considerable current, say from left to right, will pass no current, or very little, from right to left. This means that *a crystal has a comparatively small resistance in one direction and a very large resistance in the opposite direction.* For all practical purposes the latter resistance is so

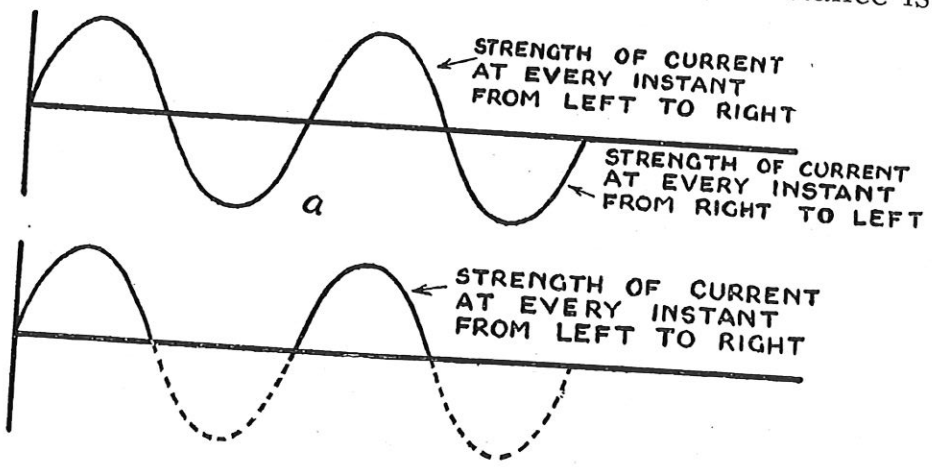

STRENGTH OF CURRENT AT EVERY INSTANT FROM LEFT TO RIGHT
STRENGTH OF CURRENT AT EVERY INSTANT FROM RIGHT TO LEFT
a
STRENGTH OF CURRENT AT EVERY INSTANT FROM LEFT TO RIGHT

FIG. 438

large that it is usual to refer to crystals as *unidirectional* or *unilateral* (one-way) conductors.

If you recollect a valve also possesses this property of unilateral conductivity; it will pass a current from the filament to the anode, but not from the anode to the filament (inside the valve).

What does this unilateral conductivity, i.e. conductivity in one direction only, mean? As you know, an alternating current is a current which flows in one direction one half-cycle and in the opposite direction the other half-cycle (see Chapter III, *Electronic Currents*). If such a current is applied to a crystal, it will be able to pass in one direction only, as the electrons trying to pass in the opposite direction will be stopped. In this manner a crystal will alter the character of an alternating current and will convert it into a unidirectional current, i.e. a current flowing

in a series of pulses in one direction only. Such a current is said to be a *rectified current* and can be shown graphically, as in Fig. 438, in which (*a*) shows the graphical representation of the current before rectification, while (*b*) shows the same after rectification. As you see, rectification means that each half-cycle in the one direction is wiped out, i.e. no electrons are flowing during that half-cycle.

For the purpose of rectification, i.e. detection, it is necessary to use a point contact between either a metal wire and a crystal or two crystals, as shown in Fig. 439.

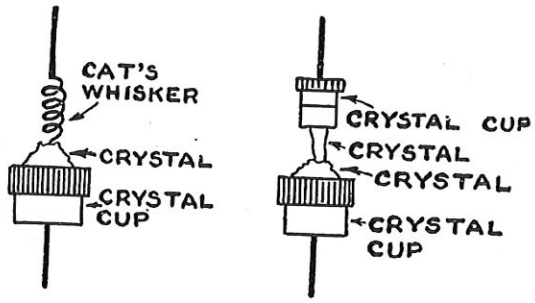


FIG. 439

There are also some crystals which work efficiently only when connected in series with a small battery.

A number of scientists have carried out a vast number of experiments with all sorts of crystals, and here is the result of some of these investigations.

Mr. Wichi Torikata, a Japanese scientist, published in the *Electrician* (16th September, 1910) a paper under the title "Commercial Wireless Telegraphy in Japan," and in this paper he gave the following list of crystals which are capable of acting as detectors:

I. *Ores quite Sensitive with Perfect Contact.*

Oxides.	*Sulphides.*
Zincite	Molybdenite
Tenorite or Melaconite	Galena
Cassiterite	Zinc Blende
Anatase	Chalkosite
Arkansite	Iron Pyrites
Pyrolusite	Pyrrhotite
Wad	

Complex Oxides.

Micacious Hæmatite
Ilmenite, Iserite, Hystatite
Magnetite
Psilomelane

Complex Sulphides.

Nagyagite
Tennantite
Enargite
Boulangerite
Schwatzite

Metallic Combinations.

Lolingite
Meteorite
Smaltite

II. *Ores Sensitive with Light Contact.*

Complex Sulphides.

Siegnenite
Copper Pyrites
Cobaltite
Ullmanite
Bornite
Sylvanite
Arsenic Pyrites
Arsenic
Graphite

Sulphides.

Marcasite or Kyrosite
Covellite

Metallic Combinations.

Niccolite
Domeykite
Strutterudite
Allemontite
Iridosmine

This is what Mr. Wichi Torikata says about these crystals:

"Nearly all ores with good conductivity can be used as detectors; but some of them require very light contact and delicate adjustment and are not practicable. The action of mineral detectors seems to depend upon the chemical and physical properties of the ores and also upon the condition of the contacts, but not upon the crystalline structure and axis of the ores." (I don't quite agree with this statement.—AUTHOR.) "Generally, the resistance of copper pyrites is very low, and that of zinc blende is very high, and they cannot be used as practical detectors when they are inserted alone between two metal

There is also a number of commercial combinations on the market, some of which are highly successful. Of such combinations the best known is carborundum, due to General H. H. C. Dunwoody, U.S.A. (U.S.A. Patent No. 837616).

Carborundum is a product of combination of salt, sand, sawdust, and coke, fused at a temperature of about 1,000 degrees Fahrenheit in an electric furnace! At low temperature carborundum has a very high electrical resistance, which, however, decreases rapidly under heat. A polarising battery of 1.25 volts is sometimes used. (Some crystals are, so to say, born rectifiers, and will rectify without additional batteries, but others will do their work best if they have a small "polarising" battery in series. The reason for this will be discussed later.)

Silicon and Brass point.—A patent by G. W. Pickard (U.S.A.). Silicon is highly sensitive in its pure state, but the commercial silicon contains a certain quantity of metallic calcium, and as this metal is quickly attacked by air, a film of calcium hydride soon covers the silicon surface and then practically all detector action stops.

Another patent of Pickard is the *Pericon* detector. The Pericon detector is a combination of zinc oxide (ZnO) and copper pyrites ($CuFeS_2$). It is twice as sensitive and more easily adjusted than the silicon detector.

L. W. Austin patented in U.S.A. a combination of tellurium-aluminium and tellurium-silicon. These two are sensitive detectors with or without polarising batteries.

Mr. Philip R. Coursey, in his book *Telephony Without Wires,* gives the following combination as most suitable for broadcasting reception purposes:

Pericon (zincite - chalcopyrite), carborundum - steel, zincite - tellurium, silicon - steel, molybdenite - copper, galena-graphite.

In his opinion the carborundum-steel, pericon, and zincite-tellurium combinations are the most stable, and least liable to disturbance by either mechanical vibrations or atmospherics.

The carborundum-steel detector requires an additional battery of about one volt. The Pericon and zincite-tellurium require no batteries.

For the benefit of those readers who may take up the

crystal work seriously, I shall give the following brief particulars of various crystals, which occur in nature. Only the more interesting and less costly crystals will come under review. These are placed in alphabetical order so that reference is easy.

ANATASE.—This mineral is one of the three forms of titanium dioxide (TiO_2). The crystals of anatese are small and well-developed. There are two kinds of these crystals; the most common type is represented by double pyramid crystals of indigo-blue colour with a steely shine. The second variety has numerous pyramidal faces and is of yellow colour. Anatase rectifies quite markedly. It gives much larger currents with a small applied voltage than does carborundum and is therefore a much more sensitive detector.

ARKANSITE.—See BROOKITE.

ARSENIC.—Steel-grey colour crystals with a metallic lustre. Natural crystals of rare occurrence. This substance is highly poisonous and has no outstanding merit from the point of view of detection, and, therefore, is well left alone.

BORNITE.—A natural sulphide of iron and copper (Cu_5FeS_4). Its crystals are of cubic form, and have an iridescent blue and red colour. It is frequently mixed with chalcocite and chalcopyrite. It is also known under the names of erubescite and philipsite. Bornite is used for detecting purposes in combination with zincite or copper pyrites (chalcopyrite). Such combinations will often give better results with a small battery in series, but will also work without it.

BORON.—A non-metallic element (B) having an atomic weight of 11. It is obtained as a dark brown *amorphous* powder. It cannot be used as a detector by itself, but only in combination with metals. Thus, for instance, boron dissolves in molten aluminium, and, on cooling, well-formed transparent crystals are obtained. These crystals are nearly as hard as diamonds.

BROOKITE.—Belongs to the same family as ANATASE and ARKANSITE, and is one of the three varieties of titanium dioxide (TiO_2). There are two types of brookite crystals; the common type is thin and tubular and is terminated by a number of small faces. The colour is reddish-brown. The second type is a crystal having the shape of a six-sided bi-pyramid of black colour and is known as ARKANSITE. It is interesting to note that brookite abounds in the neighbourhood of Fronolen, near Tremadoc, in North Wales, where it is to be found with crystallised quartz, albite, and anatase. From the point of view of detection, brookite has about the same sensitivity as anatase.

CASSITERITE.—This is a common ore of tin. It is a tin dioxide (SnO_2), and is found in nature in the form of four- or eight-sided prisms. Pure cassiterite is colourless, but usually it is impure and has a dark brown colour, if not black. It is nearly as hard as quartz.

CERUSSITE.—Cerussite is a lead carbonate ($PbCO_3$) and is an important ore of lead. Its crystals are fairly common, are colourless or white as a rule, but may have sometimes a grey or greenish tint. They are very brittle. Cerussite is associated with galena and is the product of the action of carbonated water upon galena. Cerussite is a better detector than carborundum and does not require a polarising battery. The American trade name for this crystal is Cerusite.

CHALCOCITE (Copper glance).—This is a mineral consisting of cuprous sulphide (Cu_2S). The crystals are of lead-grey colour with a metallic lustre, and are very soft. They become dull and even black on exposure to light.

COBALTITE.—A brittle mineral, being of the nature of cobalt sulpharsenide (CoAsS). The white-silvery, red-tinged crystals are frequently well developed and have a cubic form.

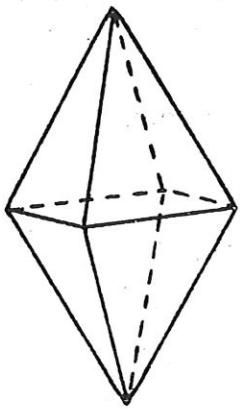
COPPER PYRITES (CHALCOPYRITE).—This mineral is, similarly to bornite, a copper iron sulphide ($CuFeS_2$). The crystals are widely distributed and are of brass-yellow colour with a metallic lustre. On exposure they easily tarnish with a predominating blue colour. These crystals resemble in appearance the crystals of iron pyrites, but can be distinguished from the latter by a deeper colour and lower hardness. While chalcopyrite can be easily scratched with a knife, the iron pyrites are scratched with difficulty.

Chalcopyrite is used for detecting purposes, either with zincite or tellurium as a pair. These pairs require a polarising battery, but considerable rectification can be obtained without it. Such a combination is desirable for use where adjustments may be frequent, due to vibrations or similar disturbances which may be present, as in the case of portable receiving equipment.

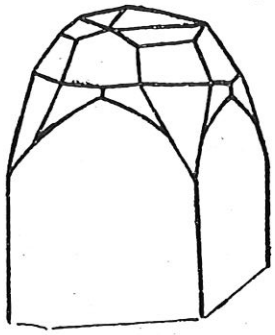
COVELLITE.—A mineral consisting of cupric sulphide (CuS). Cyrstals are rare. The colour is indigo-blue. The crystals of cupric sulphide were first discovered in the lava from Vesuvius, by N. Covelli, hence the name.

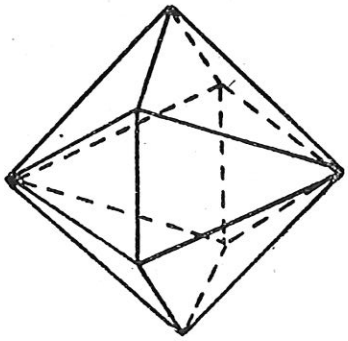
CUPRITE.—This is cuprous oxide (Cu_2O) crystallising in the cubic form. The crystals are well developed and are quite common. Their colour is red, but they soon tarnish when exposed to light and become dull. Artificial crystals of cuprite may be found in furnace products, which represent a happy hunting-ground for the crystallographer.

GALENA.—This is lead sulphide (PbS). The crystals of galena are of cubic form and are quite common. The colour is lead-

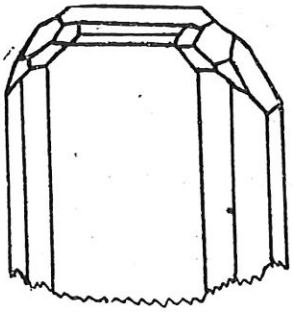


ANATASE

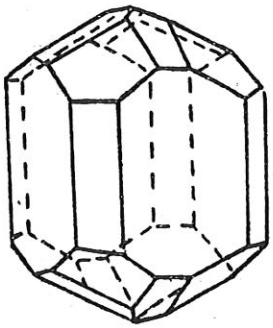




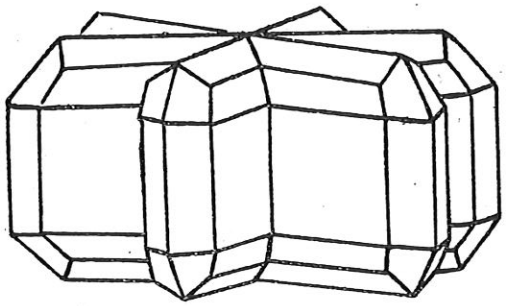
ARKANSITE



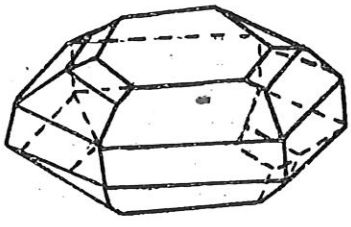
BROOKITE



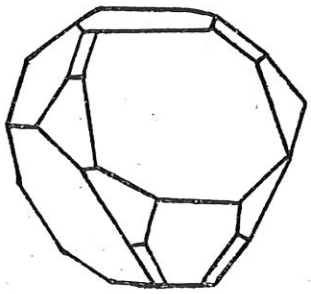
CASSITERITE



CERUSSITE



CHALCOCITE



CHALKOPYRITE

grey. Derbyshire, Cumberland, and the Isle of Man abound in this mineral, and it is interesting to note that on the Isle of Man galena crystals measuring nearly a foot across were found. For detection purposes galena can be used with a brass point. Galena-graphite forms a detector of medium sensitiveness, but reliable and insensitive to mechanical vibrations. Mr. G. G. Blake, in his book *History of Radio Telegraphy and Telephony* (Chapman and Hall), a book, by the way, which is indispensable to any would-be radio inventor, in describing the Lepel Company's detector, which consists of a galena-plumbago (pencil-lead) combination, states the following interesting fact:

"The author recalls an experiment shown to him by Mr. Marchant, who was then in charge of that station (Whitton Station, near Twickenham), by which he showed that this form of detector was not only sensitive to the received high-frequency oscillations, but was also sensitive to heat radiations. When a match was struck in the vicinity of this detector a sound was distinctly audible in the phones." He adds:

"In the light of the modern discovery of the photo-electric properties of certain contacts it is probable that this effect was due rather to light than to heat."

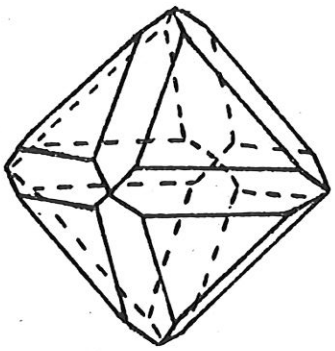
GRAPHITE.—This is a mineral species of the element carbon, the other form of which is diamond. Although diamond is the hardest crystal known, graphite is quite soft and soils everything it touches. While diamond is a bad conductor of electricity, graphite is a good conductor. The crystals of graphite, six-sided plates, are badly developed, are greasy to touch, but possess a bright metallic lustre. The external characteristics of graphite are thus remarkably similar to those of molybdenite. Graphite is used in the manufacture of microphones, grid-leaks, and electrical resistances. As a detector it is used in conjunction with galena.

HYSTATITE.—See ILMENITE.

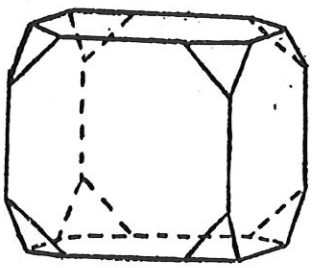
ILMENITE.—This mineral is also known as titanic iron. Its crystals reach as much as 16 pounds in weight, and are of iron black colour. The mineral is slightly magnetic, but is without polarity. The composition of ilmenite is not yet well understood, and there are several varieties distinguished by other names, of which *Hystatite* and *Iserite* are two.

IRON PYRITES.—This is iron disulphide (FeS_2). There are two types of crystals, of which one is cubic and represents the iron pyrites, while the other type is orthorombic and is known as MARCASITE. The colour of iron pyrites is pale yellow, while marcasite when untarnished is tin-white. The mineral is widely distributed. Marcasite is also sometimes called *kyrosite*.

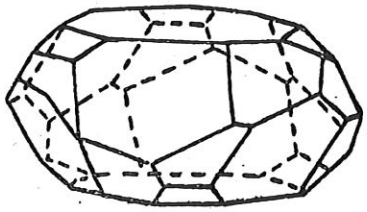
MAGNETITE.—An oxide of iron (Fe_3O_4), an important iron ore which is naturally magnetic. In colour it is iron black with



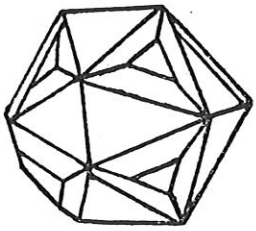
CUPRITE

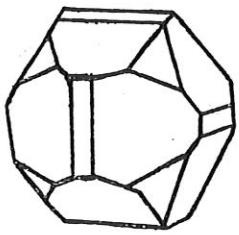


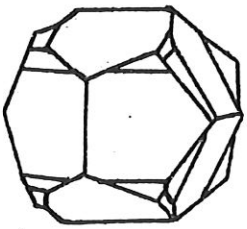
GALENA



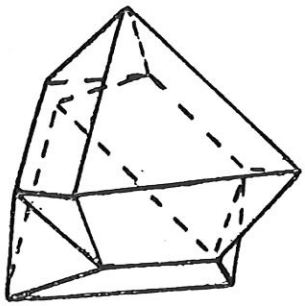
ILMENITE



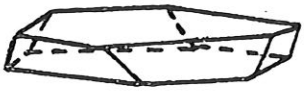




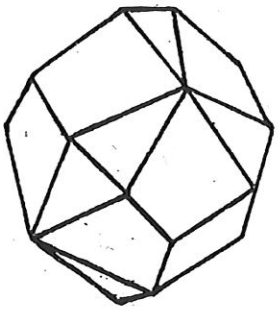
IRON PYRITES



MAGNETITE



MICACIOUS
HÆMATITE



ZINC BLENDE

a metallic lustre. It is widely distributed and occurs in many heavy and volcanic rocks. At Magnetogorsk, in Russia, there is a mountain three miles long, two miles broad, and 1,000 feet high, and from top to bottom it is one solid mass of magnetite, which crops out on the surface. It is estimated that it contains 170,500,000 tons of pure magnetite.

METEORITE.—This name is given to masses of matter which fall upon the earth's surface from the outer space. The minerals of which meteors are composed, with very few exceptions, are quite common and are to be found in the earth's crust. Where these meteors come from is not yet known, but it is assumed that they are bits of disintegrating cold celestial bodies.

MELACONITE.—An alternative name is Tenorite. This is cupric oxide (CuO). The crystals of cupric oxide are rare and appear as triangular or hexagonal thin laminæ of steel-grey colour. These crystals can be found in the Vesuvian lava and also in Cornwall.

MICACIOUS HÆMATITE.—Generally speaking, hæmatite is ferric oxide (Fe_2O_3). Crystals of hæmatite are of dark colour nearing iron black. The micaceous hæmatite consists of steel-grey scales, greasy to the touch. It is to be found in Devonshire.

MOLYBDENITE.—Molybdenum disulphide (MoS_2). Resembles graphite closely in its appearance. Molybdenite is very soft and leaves a bluish-grey mark on a white surface. The crystals are in the form of tubular hexagonal prisms of lead-grey colour having a metallic lustre. They can be readily electroplated with copper, so that connecting wires can be soldered to them. The two crystals, molybdenite-copper, used as a pair form a reliable detector.

NAGYAGITE.—See TELLURIUM.

NICCOLITE.—This is a mineral consisting of nickel arsenide (NiAs). The hexagonal crystals are of pale coppery colour having a metallic lustre. They are comparatively rare.

PSILOMELANE.—Psilomelane is a common and important ore of manganese, occurring under the same conditions as pyrolusite. It consists of hydrous manganese oxide with traces of barium, potassium, etc. This mineral is amorphous and occurs as a stalactic mass of shining surface.

PYROLUSITE.—Also an important ore of manganese, consisting of manganese dioxide (MnO_2). It is also generally amorphous, soft and black in colour, with a metallic lustre. There are, however, crystals of manganese dioxide which are exceedingly rare and go under the name of *polianite*. Pyrolusite is a variety of manganese minerals of which the others are manganite, rhodochrosite, rhodonite, etc. It is found in irregular masses in clay.

PYRRHOTITE.—A form of iron sulphide with traces of nickel and cobalt. The crystals are hexagonal plates of bronze-yellow

colour with a metallic lustre. This mineral is magnetic and is referred to sometimes as magnetic pyrites. Crystals of pyrrhotite have been found in meteors.

SILICON.—A non-metallic element (Si). (See Chapter I, *Matter and Energy.*) Silicon is to be found in two forms, one amorphous and the other crystalline. The amorphous variety is a brown coloured powder, while the crystals are grey. It is widely distributed. Silicon is used in the Pericon detector. (See previous remarks about silicon on page 559.)

SMALTITE.—This is cobalt diarsenide, which crystallises in the cubic system. The crystals are not well-developed and are somewhat rare. The colour is tin-white to steely-grey, and there is a metallic lustre.

SYLVANITE.—See TELLURIUM.

TELLURIUM.—Tellurium is a chemical element (Te). (See Chapter I, *Matter and Energy.*) It is found in nature in uncombined condition, but there are also combinations with other metals in the form of tellurides. *Sylvanite,* black tellurium, and tertadymite are examples of this. Tellurium is a brittle silvery-white substance and can be obtained in the form of brilliant prismatic crystals.

Tellurium and zincite, of which the author has had a good deal of experience, form one of the best combinations for detection purposes. No polarising battery is required, and the combination is very insensitive to mechanical shocks or atmospherics. SYLVANITE is a combination of tellurium, gold, and silver, and forms a fairly good rectifier. NAGYAGYTE, or black or leaf tellurium, is a combination of tellurium, antimony, sulphur, gold, and lead, and can also be used for rectifying, i.e. detecting purposes.

WAD.—This is an earthy form of psilomelane. The mineral is of black earthy colour and consists chiefly of hydrated manganese dioxide. It is an amorphous substance varying a good deal in its composition. There is a variety containing cobalt oxide called *asbolite* and also a cupriferous type, *lampadite.*

ZINCITE.—This mineral consists of zinc oxide (ZnO) crystallising in the form of a hexagonal pyramid. The colour is blood-red. White or yellowish crystals of zincite are often found in the residue of zinc furnaces. Zincite can be used with a brass point or in combination with tellurium or chalcopyrite.

ZINC BLENDE (Sphalerite).—This is a naturally occurring zinc sulphide (ZnS). The crystals are formed in the cubic system with six planes of symmetry. Chemically pure zinc blende is transparent, but owing to the usual presence of iron, it more often has a colour varying from yellow to brown and black, the colour depending on the amount of iron present. The crystals are quite common.

§ IV

THE INFLUENCE OF EXTERNAL CONDITIONS ON CRYSTAL DETECTORS

It is rather a difficult matter to judge the comparative sensitiveness of two crystal detectors, because many factors have to be taken into consideration and the tests have to be carried out under exactly the same conditions, but the following are the general properties which a good crystal detector should possess.

(1) It should be mechanically strong and well constructed. This means that it should be able to hold its adjustment and not be easily disturbed.

(2) The crystal should be sensitive, that is, should possess good rectifying properties, if its setting is properly adjusted. Too great sensitivity is not desirable, as satisfactory adjustment is usually obtained with difficulty. Also it may be difficult to retain the sensitive adjustment.

(3) The crystal should be easily adjusted. It is a distinct disadvantage if any marked difficulty is found in adjusting the setting for good reception, as valuable time may be lost in this way if a signal is coming in and the detector is not operating properly.

(4) The crystal should possess self-protecting characteristics, to prevent itself from being "burnt out" and the setting destroyed, if abnormally powerful radiations are received, such as static and other atmospheric disturbances.

Ordinarily, all points on a crystal are not equally sensitive, and it is necessary to adjust for maximum sensitivity by searching for best spots. The adjustment of the detector can be made, either while receiving signals or before actual reception, by exciting the receiving set by means of weak local oscillation from a buzzer.

Messrs. V. A. Hunt and L. E. Whittemore have carried out extensive tests on different crystals under varying conditions of *temperature, pressure,* and *humidity,* and the following are the results of their investigations as given in their paper, "Some Characteristics of Crystal Detectors" (*Phys. Rev.*, 7, pp. 518-528, May, 1916).

Galena.—A galena crystal and a brass point were used in this test. Rectification falls off very rapidly with the rise of temperature. There is no rectification at a temperature of 170 degrees Centigrade. A maximum rectification on cooling was found to occur at about 50 degrees C. One of the greatest difficulties in cooling the detectors below zero was the precipitation of frost upon the crystals. If the frost melted owing to the heating at the contacts, the effect of humidity was superimposed upon that of the temperature. *The presence of a very small quantity of moisture is sufficient to reduce greatly the rectification of galena.*

Pericon.—The effect of temperature is more marked than on any other crystal. Rectification ceases at about 140 degrees C.

Immersion in liquid air causes a complete loss of rectification. There appeared a definite decrease in rectification with an increase in humidity, though not to such a marked extent as in the case of galena.

Silicon.—The rectifying action of silicon was found to be very erratic. Different specimens show opposing characteristics when heated. At low temperatures it was found impossible to obtain consistent results. The behaviour of silicon under changes of humidity resembles that of the Pericon detector, rectification decreasing somewhat with the increase of vapour pressure.

Carborundum.—To secure a good adjustment with carborundum a considerable pressure on the contact point was necessary. Successive tests showed a maximum rectification at about 130 degrees C., and then it fell off to a minimum at about 165 degrees C. Above that temperature the rectification again increased. Rectification completely ceased at —85 degrees C. With each of the four detectors, as far as could be observed, change in air pressure had no effect on rectification.

With one adjustment rectified current would pass from the crystal to the metal point, and with another would flow in the opposite direction. The most common direction of rectification for silicon and galena was found to be from the crystal to the brass point. In the case of carborundum, the ordinary sense of rectification was found from needle to crystal. The Pericon detector was the

only one of the four which showed no reversal, always rectifying from chalcopyrite to zincite.

At certain times, when rectification was specially good, a humming sound was heard in the receiver similar to the inductive hum often heard when the detector circuit was opened. This seems to be evidence of the formation of a high resistance film at the point of contact.

§ v

THE RECTIFYING CHARACTERISTICS OF CRYSTALS

We know that an ordinary metallic conductor obeys Ohm's law, and if its voltage current characteristic is plotted, it may be seen that it is represented by a straight line, i.e. the current is directly proportional to the voltage, provided that the resistance of the conductor remains constant. Let us take a concrete case of a conductor having a constant resistance of 10 ohms. Let us assume that we vary the voltage applied across this conductor in steps of 10 volts, then our currents will be as follows (please remember that current equals voltage divided by resistance):

Voltage.	*Resultant Current.*
10 volts	1 ampere
20 ,,	2 amperes
30 ,,	3 ,,
40 ,,	4 ,,
50 ,,	5 ,,

Now let us plot this as a graph with the voltages being measured off horizontally and the amperes vertically. The

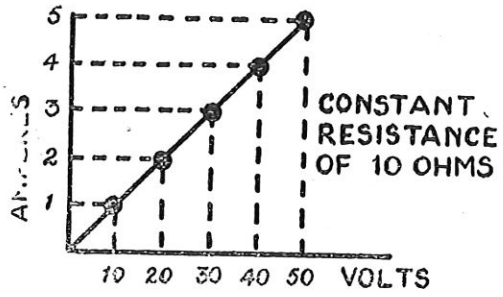


FIG. 440

graph will appear as in Fig. 440. A crystal does not behave in the same manner; in other words, it does not obey

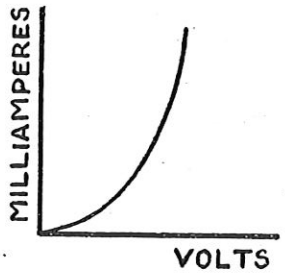


FIG. 441

Ohm's law. Its voltage-current characteristic is a curve, as shown in Fig. 441.

In the case of an ordinary metallic conductor the

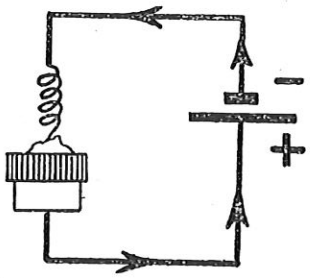


FIG. 442

reversal of voltage, i.e. the change of the direction of current, does not affect the current strength, and for two

given voltages of the same magnitude, but of opposite sign, we always get the same current, provided always that the resistance of the conductor remains the same.

With a crystal we do not get the same result. Two volts applied as in Fig. 442 may give a current 1,000 times

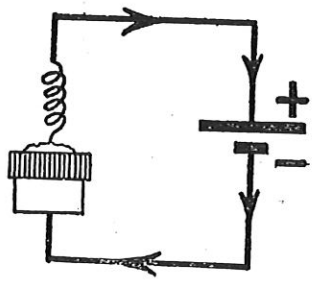


FIG. 443

greater than when the two volts are applied as shown in Fig. 443, and vice versa.

It appears, therefore, that, for some reason or other, *a crystal has a greater resistance in one direction than in the other,* and is thus capable of rectifying alternating currents, being more or less an unidirectional conductor.

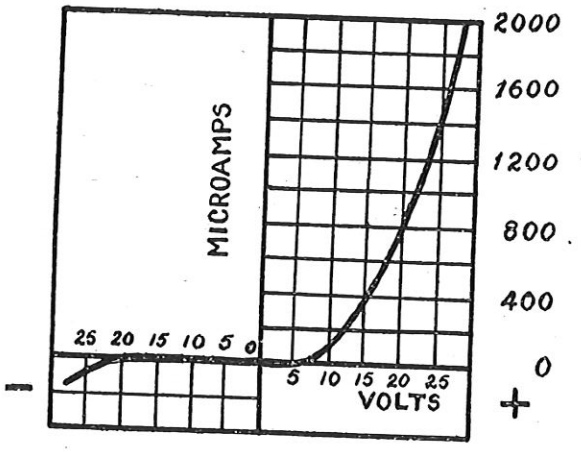


FIG. 444

The rectifying properties of different crystals differ and their current-voltage characteristics give at a glance their rectifying properties.

In Fig. 444 is given the current-voltage characteristic of carborundum, plotted by G. W. Pierce. You can see

that the curve is not symmetrical on the two sides of the middle vertical line.

When the cell is connected one way and the current is

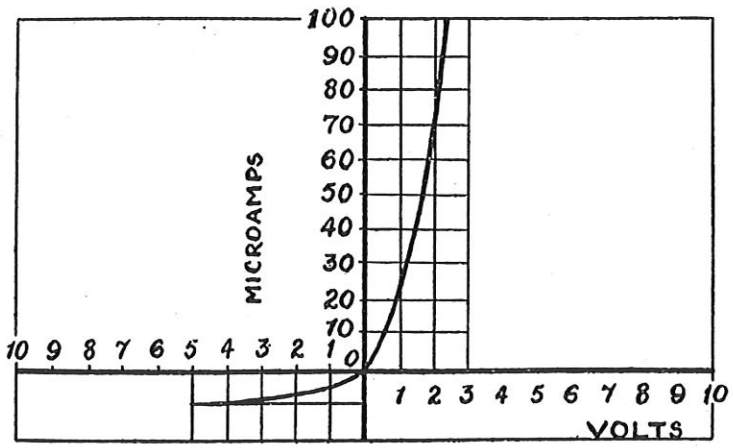


FIG. 445

flowing in the corresponding direction, it will reach a strength of 1,400 microamperes (1.4 milliamperes) at + 25 volts. When the battery is reversed (see the left-hand side of the curve), the current at —25 volts, is quite small.

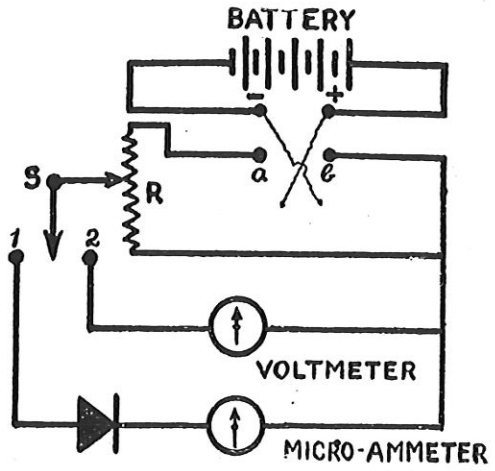


FIG. 446

In Fig. 445 a bornite-zincite curve is given. The circuit for testing the crystals and obtaining characteristic curves is given in Fig. 446. The test procedure is given in Chapter XVI, *Wireless Measuring Instruments.*

A mineral may give us one of the two types of voltage-current characteristic: an unsymmetrical or a symmetrical one. The two types are shown in Fig. 447. The graph (*a*) shows a symmetrical curve indicating that the current

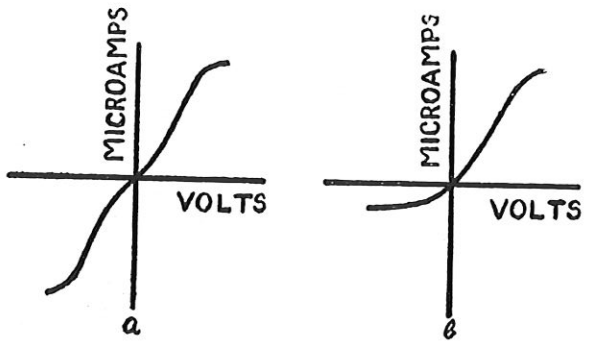


FIG. 447

passes in both directions in the same way, hence there is no rectifying action. The graph (*b*), which is an unsymmetrical one, shows that a detector is at work. Thus, in your experiments, if you are looking for a detector, the mineral under test must give you *an unsymmetrical* characteristic.

When the crystal is connected in series with a polarising

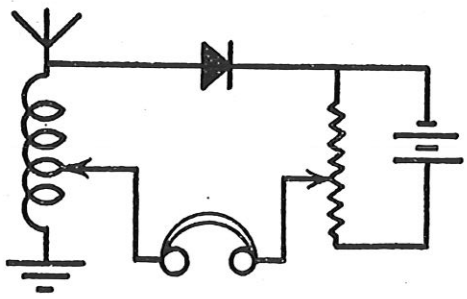


FIG. 448

battery, as shown in Fig. 448 (the tapping of the required voltage is done again with the help of the potentiometer), then an increase in the total E.M.F. due to oscillations causes a certain increase in the current flowing through the detector; an equal decrease in the E.M.F. due to oscillations, however, does not produce an equal decrease in the

current, so that different currents flow in the two directions and rectification takes place.

Brandes has shown that the rectifying action is greater:

(1) The steeper the curve towards the vertical axis at the point of voltage corresponding to the E.M.F. of the auxiliary cell.

(2) The sharper its curvature at the point of the E.M.F.

If this sharp point of curvature occurs somewhere on the curve, the point in question is the best point for work at the corresponding voltage. If the point occurs at the intersection of the two axes, i.e. at the zero point, then no polarising battery is necessary.

What the voltage of the polarising battery does is to add to the current in one direction and subtract from the current in the other direction, thus increasing the current in one direction and decreasing it in the other, or, in other words, intensifying the detector action.

As you see, owing to the different amount of resistance in the two directions, the crystal will pass a strong current in one direction and a very weak one in the other direction. It may not stop it altogether. But, provided that the difference in the intensity of the currents flowing in the two directions is large, rectification will take place. It is true that this rectification will not reach an efficiency of 100 per cent., but it will be sufficient for all practical purposes of detection of wireless signals.

§ VI

THE MYSTERY OF CRYSTAL RECTIFICATION

The reason why crystals rectify is far from being clear yet. There are several theories in existence which are of interest, and I shall give some of them below.

C. Tissot has shown that the action of a number of

detectors is very probably *thermo-electric*. Considering the combinations of metal-copper pyrites, metal-chalcocite, metal-manganese dioxide, metal-tellurium, he proved that:

(1) These detectors are sensitive only if the contact is limited to a point.

(2) They operate without a battery in series, and, when a battery is used, the sensitiveness does not depend upon the value or direction of its E.M.F.

(3) The direction of the direct current obtained under the influence of the received oscillations is always the same as the direction of the thermo-E.M.F.

With another group, however—carborundum, anatase (titanium dioxide), molybdenite, and the Pericon detector—Tissot's tests established that:

(1) The form of the contact is of little or no importance. Even relatively large polished plates placed between two metallic electrodes make sensitive detectors.

(2) The use of a battery in series with the detector, with proper value and direction of the battery E.M.F., increases the sensitiveness.

(3) The sensitiveness of these detectors bears no relation whatever to the value of their thermo-E.M.F.

He, therefore, concludes that in this last-mentioned group thermo-electric forces play no important part in their action as detectors.

G. W. Pierce, as the result of extensive investigations, including oscillograph records made with the Braun cathode-ray tube, concludes that with carborundum, anatase, brookite, and silicon, thermo-electric forces are not involved.

In testing out the Pericon detector he came to the conclusion that thermo-electric forces may be taking a part.

Mr. J. Huizinga observed *electrolytic* phenomena with the molybdenite detector and also with iron pyrites. He

found that the polarising E.M.F. is the cause of the difference in current intensities on reversal of the applied E.M.F.

The characteristic curves for these detectors were compared with those of other crystals and of the electrolytic detector. From the similarity of the characteristics it is concluded that with all the crystal detectors examined, though no products of electrolysis are visible, the unidirectional resistance is to be attributed to electrolytic polarisation in a film of moisture or a gas film adhering to the surface.

B. Thieme does not believe in thermo-electric action. Mr. Thieme's opinion is that the phenomena of rectification depend on the angle at which the current enters with respect to the crystal axis; in other words, the angle at which the entering electrons come into action.

Dr. Eccles gives the following explanation of the rectification phenomena:

" Peltier discovered that if a steady current be passed from one conductor to another of a different material, the temperature of the junction is raised if the current be in one direction and lowered if it be in another direction, i.e. heat is created or destroyed in accordance with the direction and amount of current. Now, let us suppose, as in the case of detectors of this type, that one or both of the substances has a large temperature variation of resistance.

" Suppose that an alternating voltage, such as received from the aerial wire at a receiving station, is applied to the detector, then, when the current is flowing in one direction, the temperature of the junction will rise owing to (1) the ordinary heating effect of electrical current and (2) owing to the Peltier effect." (See Chapter III, *Electronic Currents.*) " The effect will be a large diminution of the resistance and a large current will result." (We are dealing here with a point contact of two conductors, not dissimilar to an arc contact (see Chapter VI), and not with an ordinary metallic conductor the resistance of which increases with the increase of temperature.) " Since we suppose the resistance to decrease with the increase of temperature, a species of regenerative action will go on, every increase in current increasing both the

Peltier production of heat and the conductivity of the junction. A large current, therefore, passes in this direction under the influence of the applied voltage.

"When the voltage is reversed, however, during the second half of the cycle, the conditions are different. The Peltier effect for a current in this direction is cooling, and the greater the current the greater the cooling. Instead, therefore, of a great reduction of resistance, due to the cumulative effect of Peltier and the heating effect of current, we find the rise of temperature due to the latter checked by Peltier cooling, and the resistance remains high.

"With voltage in this direction, therefore, the current is very small compared with that in the other. Thus, on the whole, the current is rectified and will affect the telephones."

O. Lossev, a Russian scientist, of Nijni Novgorod, who discovered that a crystal detector can also be used for generating and amplifying purposes (are we not coming fast to an all-crystal multi-stage receiver?) is inclined to think that the rectifying action of a crystal is due to a feeble arc produced at the point of contact between two crystals or a crystal and a metal point. He stated in the *Wireless World* (No. 271, 22nd October, 1924) that ordinary detection depends upon the luminescence of the arc and that this luminescence may be observed beginning from currents of value higher than 0.1 milliampere.

As you see, the problem is still a mystery, but fortunately this does not interfere with us using the crystal for detecting purposes, and our next step is to see how the crystal detects wireless signals and causes the telephone diaphragm to be actuated. This we shall consider in the next section.

§ VII

HOW DOES A CRYSTAL DETECT WIRELESS SIGNALS?

Now, before we go any further, I want to make sure that you remember the material incorporated in the previous chapters, and for this reason I have to ask you to read once again the description of the behaviour of alternating currents in Chapters III and IV, as well as the description of the construction of the microphone and the telephones in Chapter XIV. When you have done this, please read

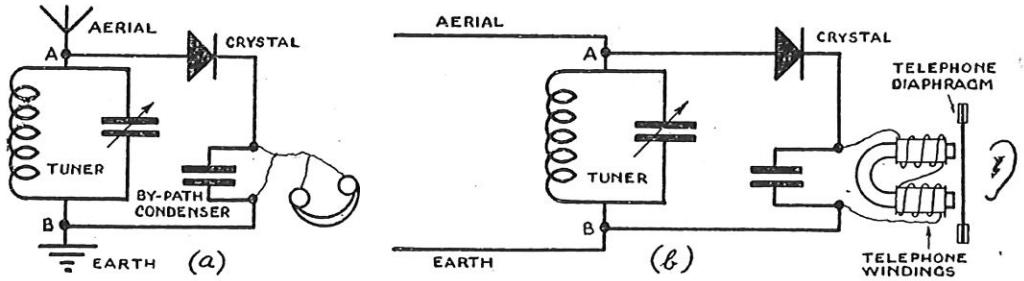


FIG. 449

carefully Section VIII in Chapter VI. Having done this (mind you do it carefully), please study Fig. 449.

The diagram (*a*) gives you a circuit of a crystal receiver consisting of a tuner (a coil and a variable condenser in parallel), a crystal detector, a "by-path" fixed condenser across the telephone terminals, and the telephones. Now, you remember from Chapter VI that such a circuit is equivalent to that shown in diagram (*b*) of Fig. 449. Here I have shown the aerial and the earth as the two plates of a very large condenser, to which the aerial-earth system is equivalent, and I have also shown the telephone windings and the diaphragm in detail.

When an electro-magnetic field appears between the aerial and earth, an electro-motive force comes into existence between the points A and B, and, since the electro-magnetic field is of an alternating (oscillating) character, the E.M.F. will be of the same character. When the tuner is tuned precisely to the frequency of the incoming

wave, the alternating E.M.F. between the points A and B will be at its greatest possible intensity at every instant ready to deliver the whole of its available energy to the receiving circuit. When the E.M.F. comes into operation, the point A, during the first half-cycle, will be gradually becoming, say, rich in electrons till the accumulation of electrons at this point will reach its maximum. At the same time the point B will be becoming gradually, but very quickly, poor in electrons, also reaching a maximum of electron "poverty" at the same instant as the point A reaches its maximum of electron "richness." For this reason a flow of electrons will be taking place, during the first half-cycle, from A, via the crystal (we are assuming that the crystal will conduct a large quantity of electrons in this particular direction), to the upper plate of the by-path condenser, as shown in Fig. 449.

At the same time, electrons will be receding from the lower plate of the by-path condenser towards B in order to reach through the tuner the point A, and so provide it with electrons to carry on with the good work. In this manner, at the instant of maximum E.M.F. across the points A and B the by-path condenser will acquire a maximum charge. When the E.M.F. across the points A and B, under the influence of the collapsing electro-magnetic wave, begins to diminish, the condenser will have a tendency to discharge, i.e. send electrons from the "rich" upper plate back to the aerial in order to compensate the latter for the electrons which the collapsing wave is dragging away to the end of the aerial; but this is where the crystal comes in; it will not allow the electrons to go back in any appreciable quantity as it passes current in one direction only, and, therefore, the electrons must, perforce, remain on the upper plate of the by-path condenser. The next natural thing for the by-path condenser to do is to try to discharge through the telephones, but at the moment the condenser does not possess a sufficiently large charge to be able to do so and let an appreciable current go through the telephone windings.

In other words, the opposition of the telephone windings is at the moment too great for the existing E.M.F. across the by-path condenser. During the second half-cycle, when the point A becomes poor in electrons and

the point B rich in electrons, there should be normally a flow of electrons from B to the lower plate of the condenser and from the upper plate of the by-path condenser to A. But, again, the crystal will not allow electrons to go in the opposite direction, i.e. from the upper plate of the by-path condenser towards A, and will also stop the movement of electrons from B, as electrons will not flow at all unless there is compensation going all round. Thus the whole of the second half-cycle will prove inoperative from the point of view of the by-path condenser, which will keep its existing charge with the help of the crystal.

During the first half of the *second cycle,* another batch of electrons will be allowed to pass to the upper plate of the by-path condenser and from the lower plate to the point B, thus further increasing the charge. And so wave after wave will contribute to the by-path condenser charge, till a train of waves has passed, a train of waves corresponding to a certain sound. At the end of the train the by-path condenser will have accumulated a sufficient charge to be able to discharge itself through the telephone windings and actuate the diaphragm.

In this manner, as train after train of waves sweeps past the aerial, the by-path condenser will discharge once during each train and move the diaphragm. You will realise that the trains or groups of waves occur slower than the individual electro-magnetic waves, but they still occur fast enough to cause a very rapid charge and discharge of the by-path condenser and, therefore, a very rapid (within the limits of audibility) movement of the telephone diaphragm. The latter is thus able to vibrate in precisely the same manner as the microphone diaphragm was vibrating in the studio, and create the same sound waves. Each time the by-path condenser discharges itself a current flows through the telephone windings, producing a magnetic field around them, magnetising the core of the windings, and exercising a pull on the soft iron diaphragm. A series of such rapid pulls will set the diaphragm vibrating. You should realise that if we are receiving on 300 metres wave-length the frequency of in the incoming wave is $\frac{300,000,000}{300}$, which

equals 1,000,000 cycles per second. If we have, say, 100 waves in each train or group, the frequency with which the trains of waves will occur and the frequency with which the condenser will discharge and therefore the frequency with which the diaphragm will vibrate will be 10,000 times a second, which is an audible frequency. The train of waves is different with each note, as each note has a different frequency, and this is how note after note follows issuing from telephones.

You see what the crystal is doing? It acts as a sort of "one-way pocket." It allows the electrons, disturbed by each wave, to accumulate on one plate of the condenser, with a corresponding migration from the other plate, but will not allow them to go back again. In this way they are trapped till they are wanted. This is where its conductivity in one direction comes in. Then, when the "one-way pocket" is full, the crystal "rings the coins" and a pleasant sound results.

The by-path condenser is not an absolute necessity. The windings of the telephone possess enough capacity of acquiring electrons, between the turns, to be able to accumulate a charge on themselves and discharge through themselves, i.e. to accumulate enough electrons on the *surface* of the wire, at the two ends of the windings, and send them going along the wire with the same effect as if the by-path condenser were present; but it is better and more efficient to have a by-path condenser across the telephones. I trust that I have made myself sufficiently clear for you to be able to understand how detection takes place in the case of a crystal, and to clinch matters I shall fall upon Fig. 450, which may help to fix our ideas on this subject. As you know, we can represent the growth and fall of alternating or oscillating currents by means of graphical representations, in which the current flowing in one direction is shown above a horizontal line and the current flowing in the opposite direction below the horizontal line. The "wobbles" above and below the line show how the intensity of the current varies in each direction from instant to instant. Such a graph can be drawn, if one records with the help of measuring instruments the strength of current from instant to instant in each direction. It only means taking a few dozen readings.

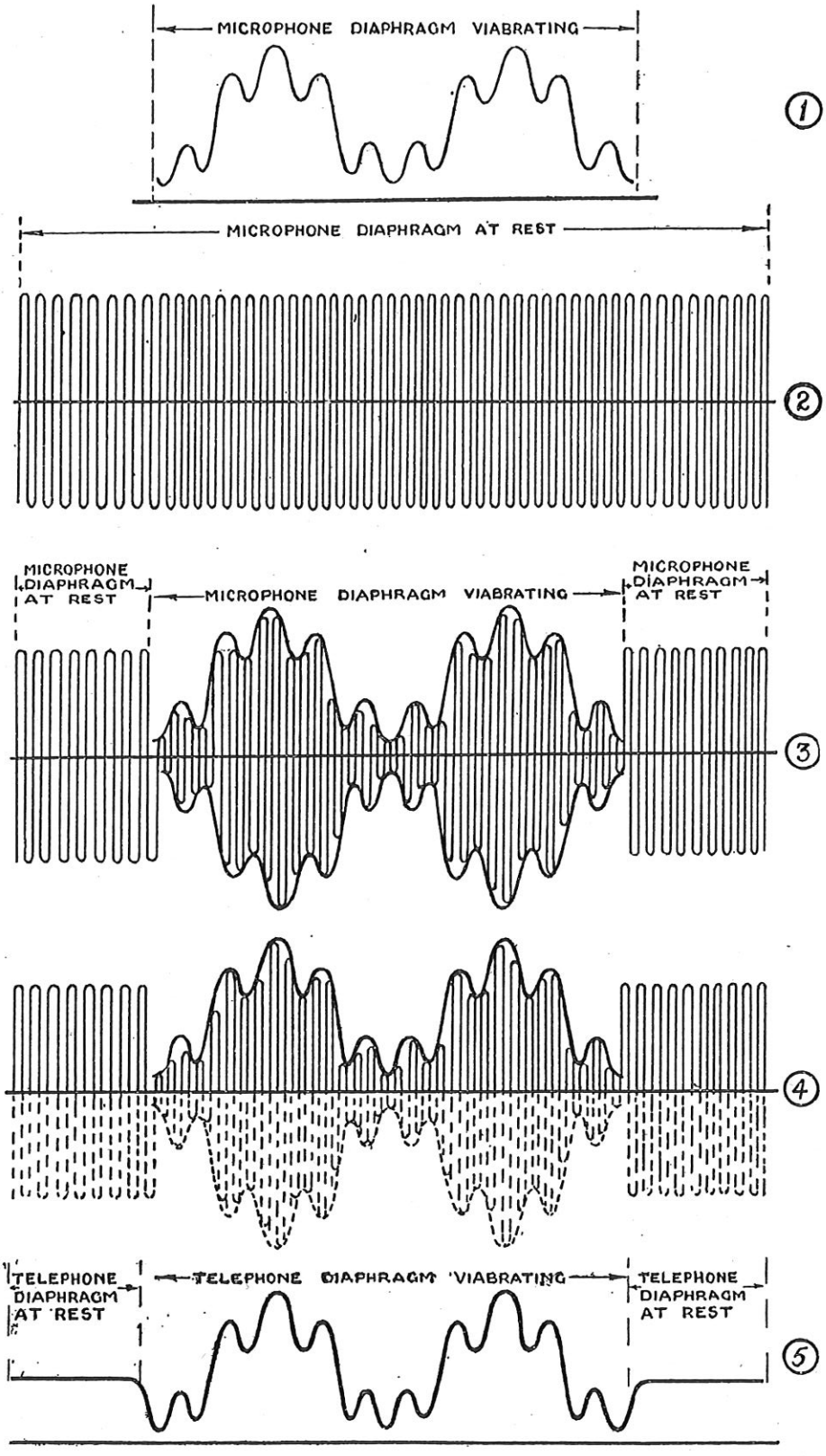

MICROPHONE DIAPHRAGM VIABRATING
1
MICROPHONE DIAPHRAGM AT REST
2
MICROPHONE DIAPHRAGM AT REST
MICROPHONE DIAPHRAGM VIABRATING
MICROPHONE DIAPHRAGM AT REST
3
4
TELEPHONE DIAPHRAGM AT REST
TELEPHONE DIAPHRAGM VIABRATING
TELEPHONE DIAPHRAGM AT REST
5

FIG. 450

Now, in Fig. 450, graph (1) represents some arbitrary variation of the unidirectional microphone current, the irregularities of which represent the variation of intensity of sound waves in the air, as emitted in front of the microphone. Graph (2) represents the carrier current flowing in the transmitting aerial before the microphonic currents are allowed to interfere with it. As you see, the carrier current is perfectly uniform. If we drew the graph of the carrier wave in the ether it would have precisely the same appearance as the graph of the carrier current, which is its cause.

When the microphonic currents are allowed to reach the transmitting aerial the character of the carrier current changes as shown in Fig. 450 (3). You will note that when the microphone diaphragm is at rest the carrier current preserves its uniformity, and only loses this uniformity and becomes impressed with the microphonic currents' characteristics, and therefore with the sounds' characteristics, when the microphone diaphragm is working.

In Fig. 450 (4) you see how the crystal has stopped the current from going through in one direction (in this case it is the current induced in the receiving aerial—a current identical in character with that circulating in the transmitting aerial) and reduced the alternating oscillations to unidirectional pulses.

As you see, all currents in the direction in which the crystal does not conduct are more or less, apparently, wiped out. The net effect on the telephone diaphragm is the average current passing as shown in Fig. 450 (5). When the rectified carrier current is flowing alone, it is perfectly uniform and its effect on the telephone windings would be to produce a steady magnetic field which would exercise a steady pull on the diaphragm, but would not cause it to vibrate. It is only when the variations come into play that the diaphragm begins to vibrate. Incidentally you will notice that (1) and (5) are identical in character, i.e. the characteristics of the current flowing through the microphone in accordance with the sound variation are the same as those of the final current flowing through the telephone windings. Since the currents are the same in character, the microphone and the telephones'

diaphragms will vibrate in precisely the same manner. If distortion is present it simply means that the character of graph (1) has been altered and that the resultant current in the telephone windings is not the same, or, in other words, the graph (5) becomes unlike graph (1). Hence the trouble, and plenty of it. Fortunately in the case of the crystal there is not much fear of that.

Although we assumed the crystal detector to be a unidirectional conductor, it is not strictly such, and will allow a small current to flow in the direction of its maximum resistance. Thus there is always a small unrectified or a *high-frequency alternating component* present in the circuit, but this is by-passed by the condenser across the telephones to earth. Such a high-frequency alternating component is only possible in crystal circuits. The corresponding component in the anode circuit of a valve is a series of high-frequency, varying in magnitude, unidirectional pulses, as in a valve a current can flow only from the filament to the anode but not back again. Even in a valve there may be a very small H.F. alternating component, due to leakage across terminals, etc.

§ VIII

THE VALVE AGAIN

Having finished with crystal detection for the time being, let us now turn to the valve. But before we go any further, please make sure that the material placed before you in Chapter X, *Modern Valves,* is fresh in your memory, and that you will know a valve characteristic curve when you meet one.

RADIO FOR ALL

BY

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EDITOR OF "RADIO NEWS"

WITH 13 HALFTONES AND 133 ILLUSTRATIONS

PHILADELPHIA & LONDON
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CHAPTER V

RECEIVING INSTRUMENTS

THE earliest and perhaps the first instrument for detecting radio waves was the coherer. This was a rather complicated little instrument, and one that was difficult to keep adjusted. Furthermore, it was not at all sensitive, compared with the detecting instruments of today. Fig. 17 shows the in-

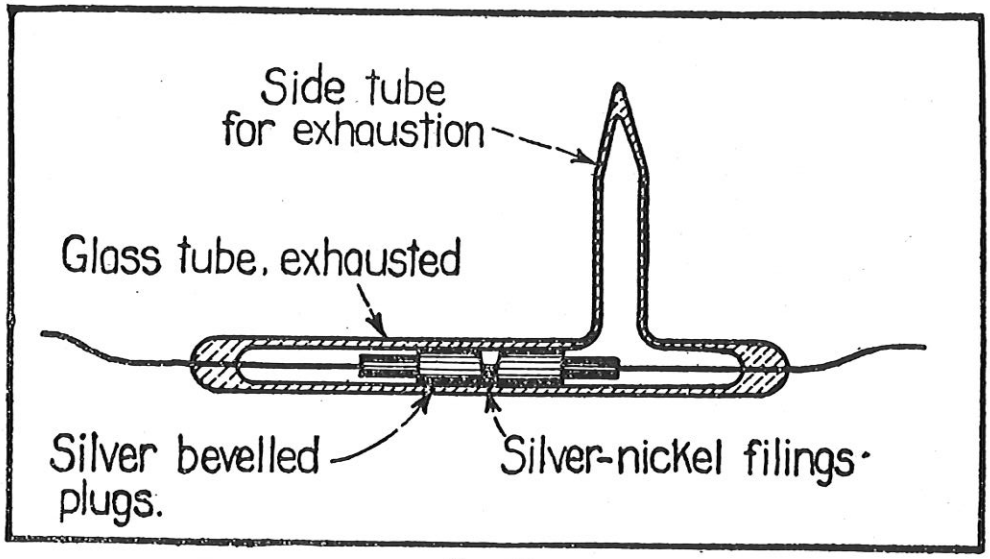

FIG. 17.

strument which was composed of nothing more than two metal plugs surrounded by a glass tube; the small space, about one-eighth of an inch, that separated the two plugs was taken up by nickel and silver filings. The proportion was roughly, 90 per cent. nickel and 10 per cent. silver. The peculiarity of this instrument was that when radio waves struck it, the filings became more conductive, and,

therefore, passed the electrical current through better. Further, it was possible to ring a bell with the coherer. The simplest connection is shown in Fig. 18. Here we see the coherer attached to the ærial and the ground, also a relay, a battery and a bell.

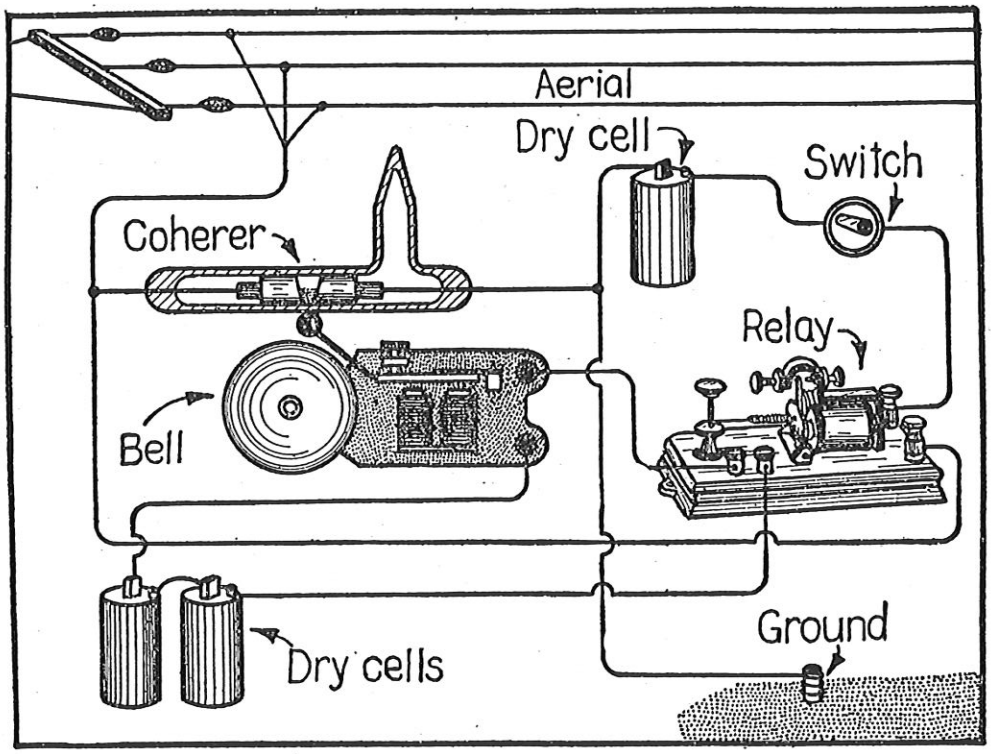

Fig. 18.

The instant that a radio wave impinged upon the ærial, the bell would ring, and would continue to ring even though the wave had passed.

In the early days, Marconi provided a sort of tapping arrangement which, hitting the coherer, disturbed the filings, destroying the conductibility, and the coherer was then ready to receive an additional signal. This instrument, however, was not very satisfactory, because it did not always respond to radio waves, and sometimes it responded to

static electricity (atmospheric disturbances) as well. This instrument, therefore, was soon discarded.

A somewhat better and simpler instrument is shown in Fig. 19. Here are two blocks of carbon filed to a sharp edge. On top of the carbon rests a sewing or darning needle; the idea is that the

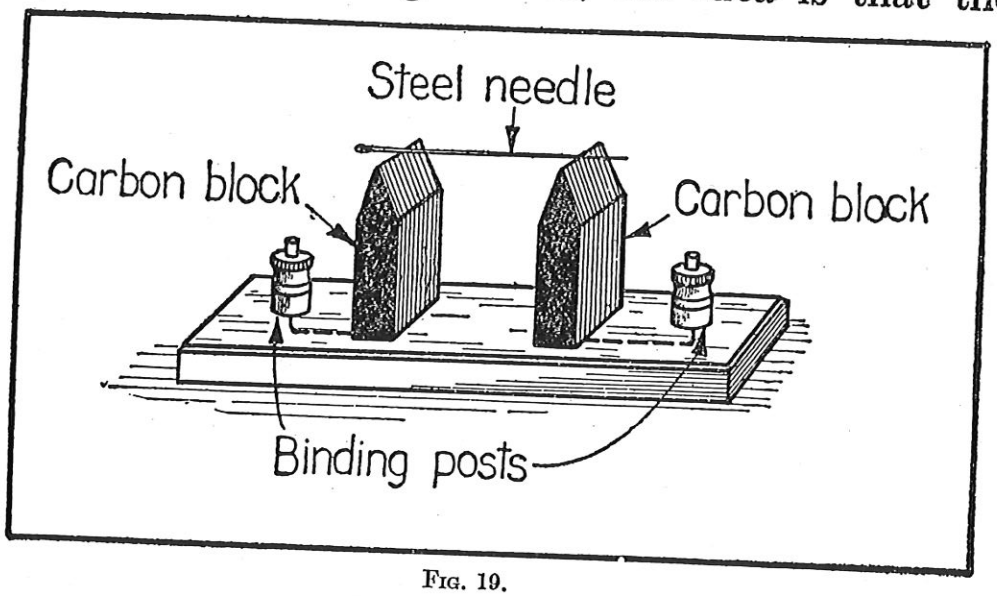

FIG. 19.

needle makes a slight contact with the carbon blocks. This was the first real detector, because unlike the Marconi coherer, it was self-restoring, that is, it needed no tapping to make it ready for the next wave. In other words, dots and dashes could be received with this detector with but little trouble. The connection is shown in the diagram, Fig. 19A, and it will be noted that a battery is required with this detector, although if adjusted exceedingly well, such an instrument works without a battery, but not so readily. Such a detector is quite unsatisfactory for the reason that the slightest vibration, such as footsteps in the room, disturbs the needle and

makes the device inoperative until it is adjusted again. This was one of its great draw-backs.

Soon afterwards there was developed the so-called electrolytic detector shown in Fig. 20. It may be considered, even today, a good detector, and while not as sensitive as the best crystal detector (this will be discussed later) it has the one great advantage in that it "stays put" and does not very easily get out of order. The electrolytic detector

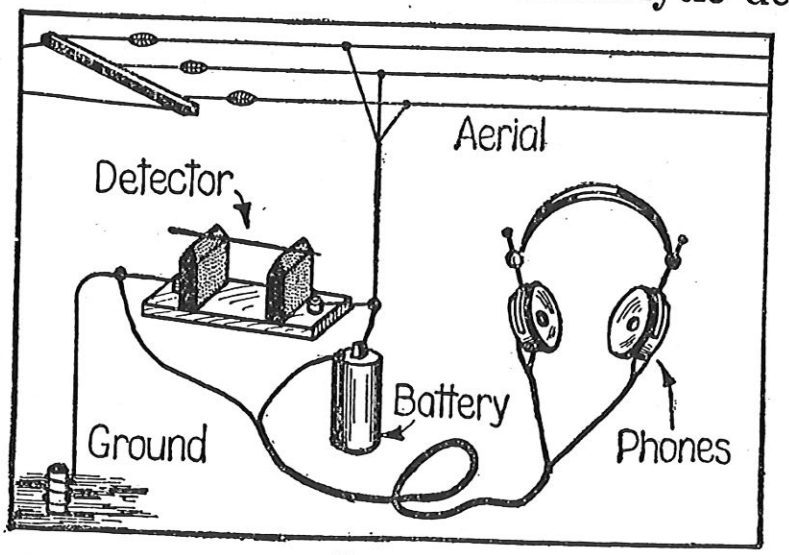

FIG. 19A.

has a fine platinum wire, as shown in the illustration that dips into a small cup containing a solution of nitric acid in the proportion of about five parts of water and one part of nitric acid. We can also use a similar proportion of water and sulphuric acid; both work very well. The wire which touches the nitric acid is exceedingly fine, for which reason it is difficult for the eye to perceive it. It is called Wollaston wire, and is a fine platinum wire covered with a heavy coating of silver.

When the wire is immersed in the acid, the silver coating is eaten away by the acid and a fine plat-

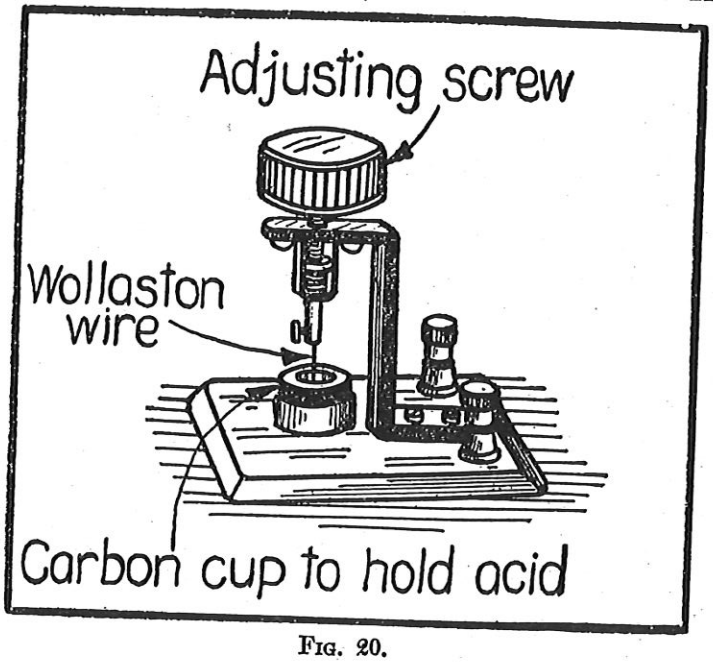

FIG. 20.

inum wire remains. This wire is less than three ten thousandths of an inch thick, so fine that it can

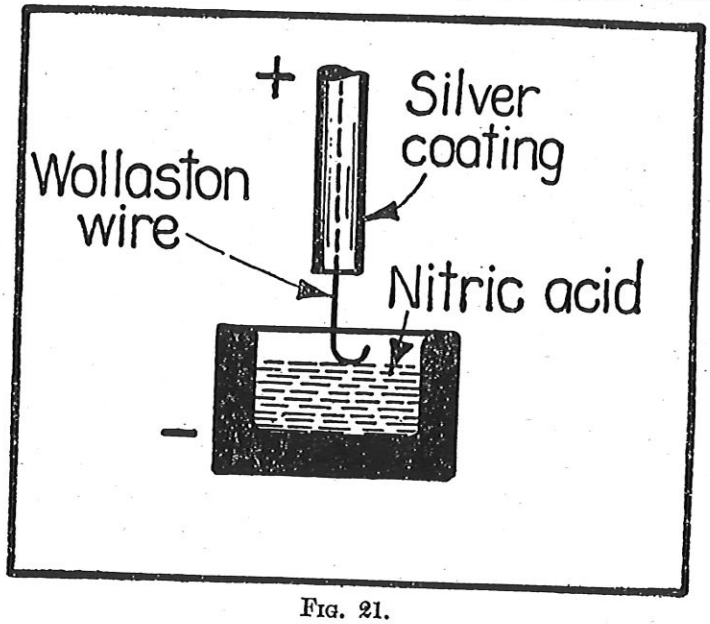

FIG. 21.

hardly be seen. Usually some sort of regulating mechanism is used to make this wire dip more or

less into the acid. As a matter of fact, the best results are had with the Wollaston wire when it barely touches the liquid, as is shown in Fig 21. The wire being so extremely thin it curls over slightly when touching the acid solution. It will be noted that with this style of detector, as shown

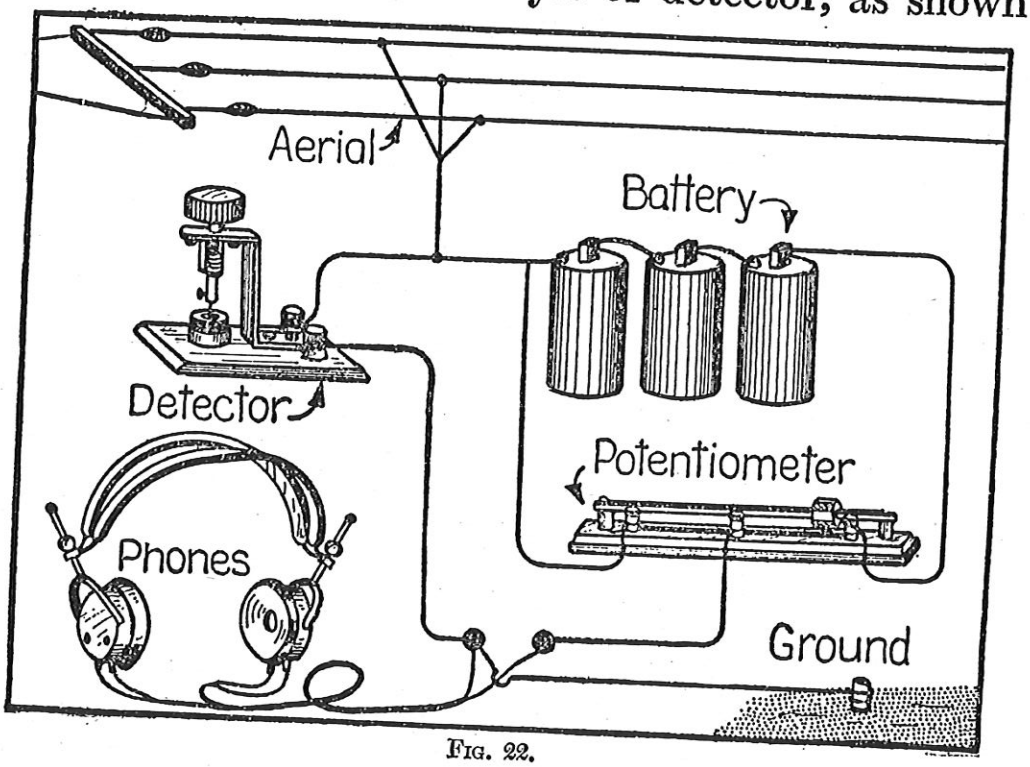

FIG. 22.

in the diagram, Fig. 22, a potentiometer is used. This potentiometer is nothing but a sort of resistance, and is employed solely to cut down the current from the batteries. High resistance telephone receivers having a resistance of 2,000 or 3,000 ohms are used with the electrolytic detector with good results. The potentiometer is adjusted until the "boiling" noise is reduced to a minimum in the telephone receivers, and the detector is now ready to receive the signals. With the electrolytic detec-

tor, signals have been received over very long distances.

The author was about the first one to introduce the use of a carbon cup in connection with the electrolytic detector, shown in Fig. 20; this carbon cup, being a conductor, made a much better instrument because metal cannot be used. Before the author's experiments, small glass vessels having a platinum wire fused into them were used, but these were rather expensive. The author also found that if a small drop of petroleum or paraffin oil was poured upon the acid, it would keep the latter from evaporating. This is quite important, as before this improvement was made, it was necessary to replenish the acid almost every day. The author who had experimented a great deal with electrolytic detectors, endeavored to develop such a detector in which no loose acids were to be used. A detector termed the "Radioson" was designed by him, and this had all the elements of the standard electrolytic detector. The fine Wollaston wire was fused in a glass tube which was immersed in the acid as shown in the illustration, Fig. 23. The Radioson was also used in connection with the potentiometer and high resistance receivers just as was the original electrolytic detector. Unfortunately the Radioson, once subjected to strong signals or even too strong static currents, would burn out the exceedingly fine Wollaston wire, after which the instrument became inoperative. Although the Radioson was perhaps

one of the best electrolytic detectors ever designed, no means could be found to keep it from burning out and the manufacture of it was given up by the makers.

Soon after the invention of the electrolytic detector, crystal detectors came into vogue. Dunwoody was perhaps the first man to use such a

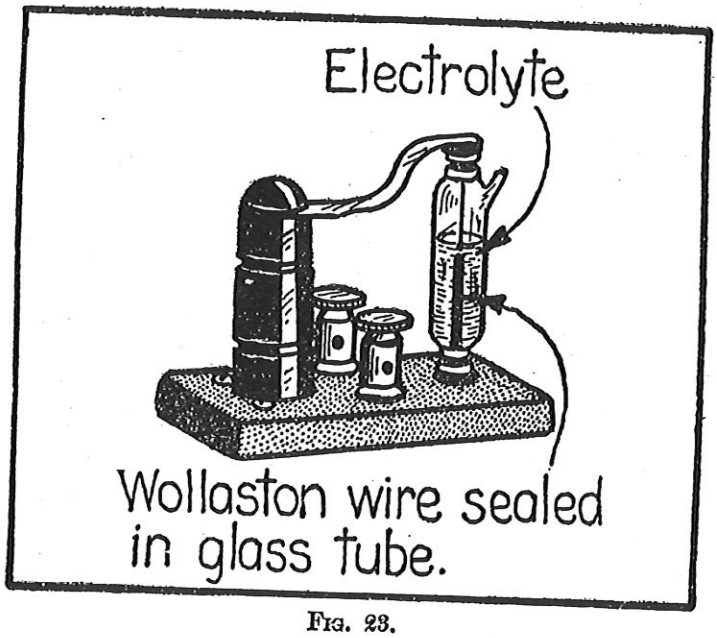

FIG. 23.

crystal, *viz.*, carborundum. The carborundum crystal is a green-bottle colored sharp crystal, which is a manufactured product. Carborundum is used mainly as an abrasive, being harder than glass, which it scratches easily. The carborundum detector is shown in Fig. 24. The connection is similar to that of the electrolytic detector and is, therefore, not shown here. As will be seen the carborundum crystal is clamped between steel needles under a certain amount of pressure, in such a way that the needles rest against the surface of the crystal. The

amount of pressure that the needles bear against the crystal is determined by experiment until the signals come in loudest. The amount of pressure varies for every crystal, and must be found by trial. Once adjusted, the carborundum detector needs no attention, and it will not get out of order readily. Jars do not affect it, and for that reason it has been

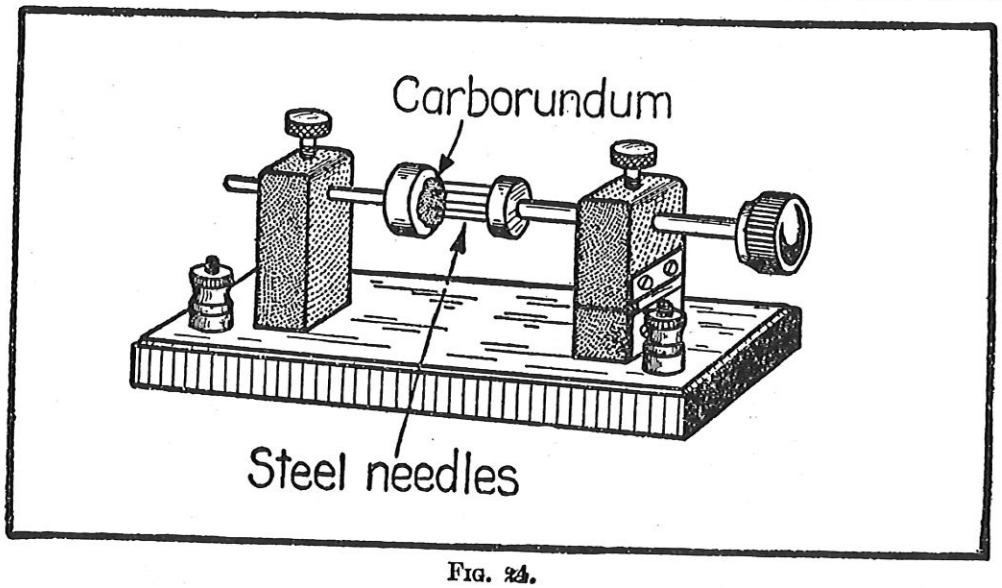

FIG. 24.

used to a great extent on board ships, in portable outfits, etc. Unfortunately, this detector is not very sensitive. As a matter of fact, it is not as sensitive as the electrolytic detector, but where stability is required this detector is excellent.

Fig. 25 shows one of the best of the early detectors, *viz.*, the silicon detector. Silicon is a manufactured substance, which is a by-product of the electric oven in the manufacture of abrasives; it is a cousin to carborundum. Silicon is a hard rock-like substance of a dark silver-gray color. The detector is shown complete in Fig. 25. A small piece

of silicon broken from a larger piece by means of a hammer or in a vice, about ¼ inch by ¼ inch, is first imbedded into a soft solder, as shown in the separate illustration of Fig. 25. The idea of this pellet is that contact is made on five sides with the metal, which is simply cast around the silicon, and the crystal part of this round pellet is after-

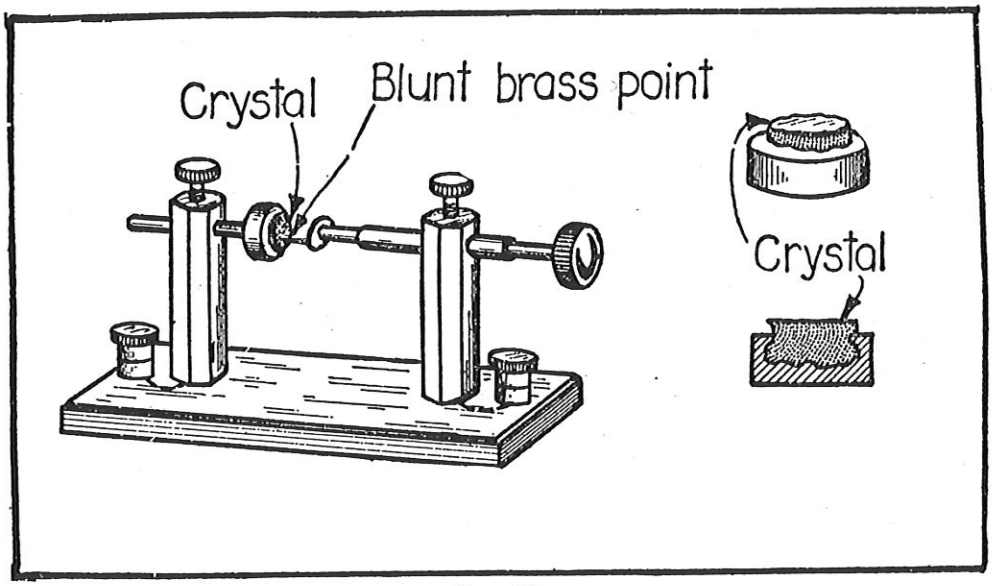

Fig. 25.

wards placed in contact with the contact member, as shown in the illustration. The contact member is nothing but a piece of brass, which is not very sharp at the end, but rather blunt. The amount of pressure upon the pellet is varied by a spring. In detectors of this kind, not every point of the silicon is equally sensitive. Some points are very sensitive while others are not. Some of the sensitive points require more pressure than others. All this is found out by experiments. The silicon detector is quite sensitive, and probably is as good a detector as the electrolytic type, with the great

advantage that it requires no battery. This was the first detector invented that required no battery whatsoever to detect radio signals, and for that reason it is a favorite instrument with the experimenter. The silicon detector has also the great advantage in that it is not easily "knocked out," as most other detectors are. It is not so sensitive to static elec-

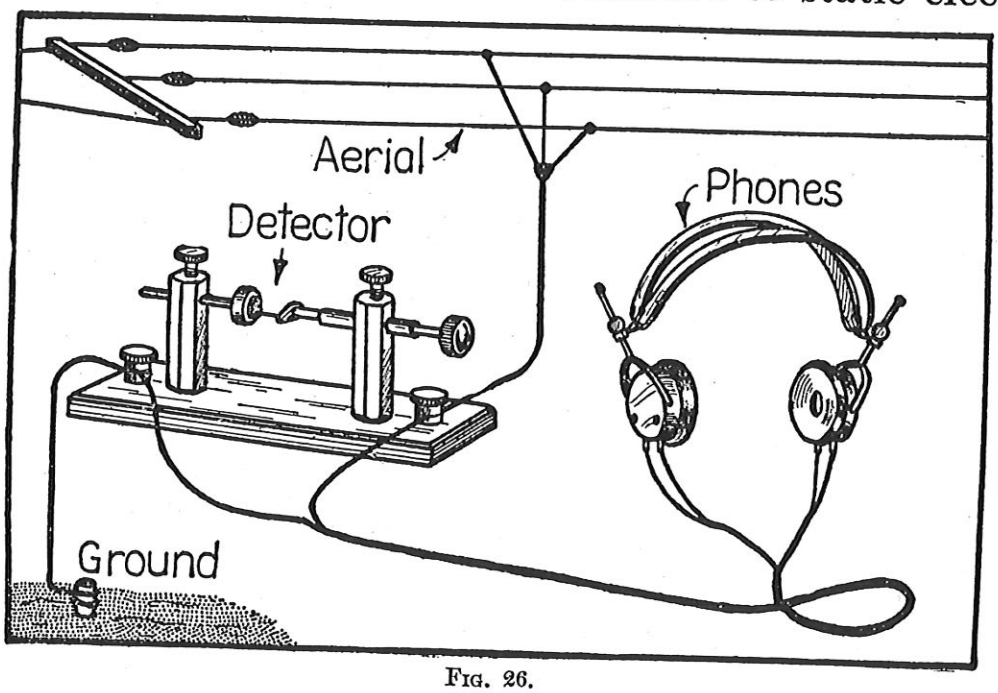

FIG. 26.

tricity and does not burn out easily. When connected, as in Fig. 26, a set of receivers of at least 1,000 ohms should be used for best results. We might state here that a 75-ohm receiver, such as is used in house phones, should never be used in connection with radio waves. The results are very poor. For short distances a 75-ohm receiver may be used, but even then it is not sensitive and not very satisfactory.

Soon after the silicon detector was invented,

Greenleaf W. Pickard, the inventor of the silicon detector, invented a host of other detectors, all of which use a native mineral crystal, such as, for instance, iron pyrite, copper pyrite, bornite, etc. All of these detectors are used similarly to the silicon detector, the crystal being cast into a soft metal in pellet form. This pellet is used in the same way as

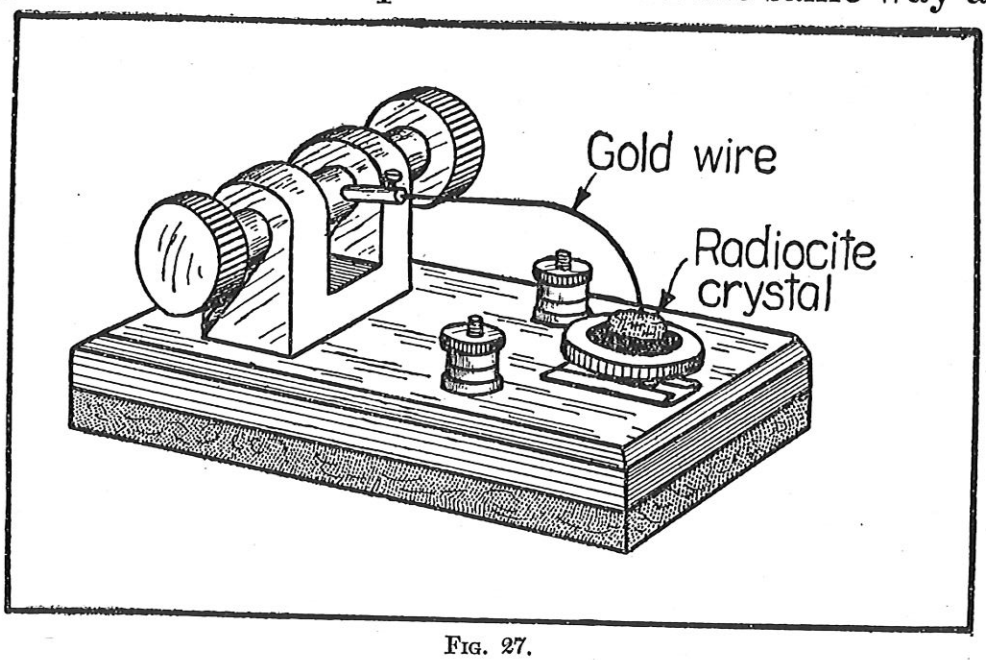

FIG. 27.

the silicon detector; sometimes a sharp brass contact point is used with some minerals and at other times a fine wire is used, which latter is termed a *Catwhisker*. Such a detector is shown in Fig. 27. This detector uses as a sensitive member the mineral or crystal known in the trade as Radiocite. Radiocite is a treated iron pyrite and is as shiny as polished gold. A good piece of radiocite is equally sensitive over its entire surface. It is probably as sensitive as any of the mineral detectors in use today. As with all other crystal detectors, no battery is used

in connection with it. In the radiocite detector no sharp point is used, but rather a fine gold wire catwhisker. A catwhisker is a piece of fine wire about No. 26 or No. 28 B & S gauge phosphor bronze. This is attached as a rule to some sort of handle or other adjusting means so that the pressure of the wire upon the surface of the mineral may be varied. If one spot burns out or becomes inoperative, a new point is found by experiment.

One of the most sensitive and most widely used detectors is made of Galena, a lead ore of which there are different grades. It is known under many trade names as well. A good piece of galena is probably as sensitive as any crystal yet discovered, but it is not stable. A catwhisker, as explained under the radiocite detector, is used with the galena crystal and the amount of pressure has to be found by experiment. Ordinary galena is not sensitive on every spot, but there are certain grades which are equally sensitive over the entire surface; this is known as Argentiferous Galena, which means that it is silver bearing. On the other hand not all argentiferous galena is equally sensitive, and there is no hard and fast rule about it. It must be found by experiment. The connection for the radiocite, as well as galena detector, Fig. 28, is the same as shown in Fig. 26. No battery is used with galena, and as a matter of fact a battery will destroy the usefulness of it by burning out the sensitive points. With galena, a fine brass wire No. 24 or No. 26 B & S

gauge is used; a stiff gold wire of the same dimension may also be used, as it is non-oxidizing. It may be stated here that most any metal wire can be used; they all work equally well with the possible exception of iron, which soon becomes coated with rust and will then no longer operate.

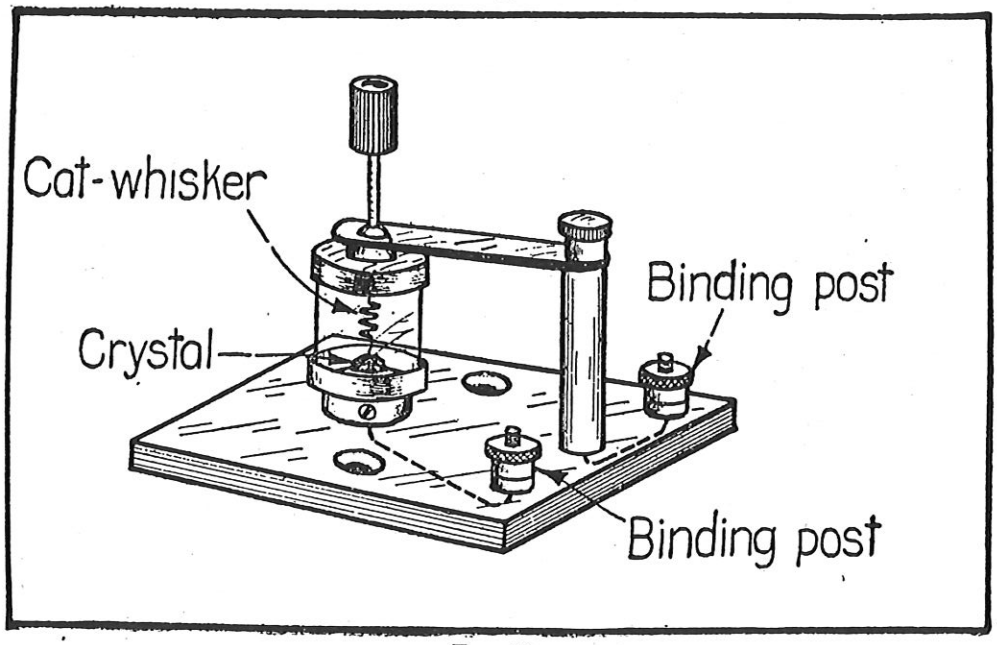

FIG. 28.

All crystals are only sensitive if absolutely clean, and their usefulness becomes destroyed immediately upon being handled with the bare fingers. The natural oil of the hands tends to destroy the sensitiveness as the crystal surface becomes coated with it. The best method to employ with all crystals is to clean them frequently with a piece of absorbent cotton moistened with carbon tetrachloride. This high-sounding name is nothing but Carbona, which may be purchased anywhere. There are some liquids advertised under high-sounding names, all of which are in reality Carbona; this does the

work 100 per cent. well, and should always be used where crystals are employed. After rubbing the crystal with the moistened cotton, it should be left

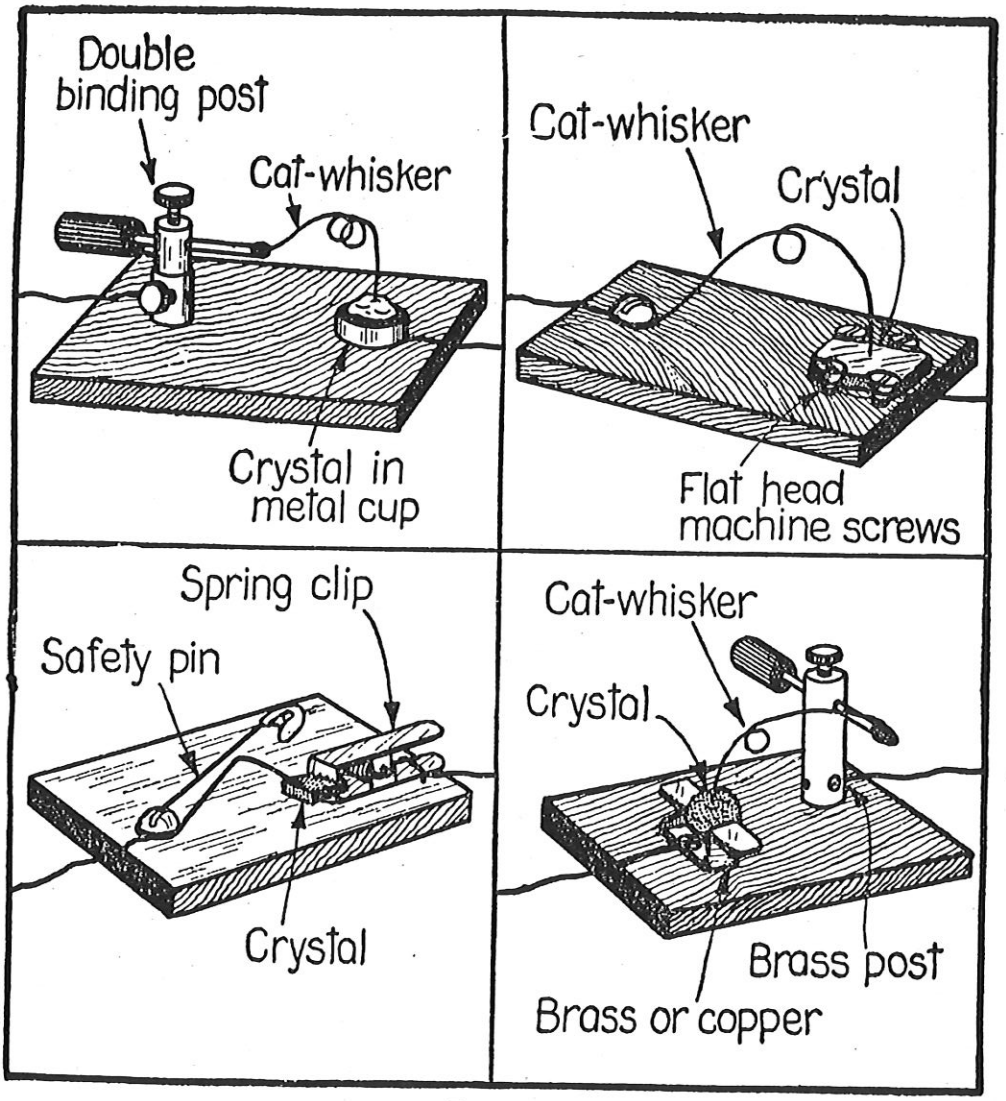

FIG. 29.

for a few minutes until the liquid has evaporated. The crystal will then be found in first class condition.

Although we have stated a little further back that most crystal detectors have the sensitive mineral embedded in a metal pellet, the amateur or experi-

menter does not always require this, and Fig. 29 shows several simple home-made detectors. The illustrations are so self-explanatory, that no further details need be given. Base boards may be of wood, hard rubber or any good insulator. As will be seen in these illustrations, the detector mineral is clamped by simple holding devices; anything that will hold the crystal down so that it will not move, and at the same time make good contact with it, may be used. The catwhisker wire is best (a No. 24 or No. 26 B & S brass gauge), or phosphor bronze wire. It may be straight, or coiled in pig-tail fashion, either will work equally well. The clever experimenter can change the design to suit his own individual tastes, and the chances are that the device will work well. The trouble with most mineral detectors is that their adjustment does not keep for any length of time. Jars, or static surges in the ærial will cause the detector to become inoperative, after which it must again be adjusted. The better the crystal and the more sensitive spots it has over the entire surface, the easier the adjustment will be.

We now come to a vastly different sort of detector, namely the Audion, or as it is commonly called, the "Vacuum Tube." This detector works upon an entirely different principle from any of the former ones described, and is in general use today for reasons which we shall learn presently. The audion makes use of a principle first discovered by Edison, and for that reason termed the "Edison

Effect." Edison found that if he placed two filaments in an ordinary electric lamp instead of one filament, and lit them both, a current would flow across the vacuum or empty space. It is this principle that is now being used in the vacuum tube. Fig. 30 shows a standard vacuum tube where we have the filament, which is the same as that used

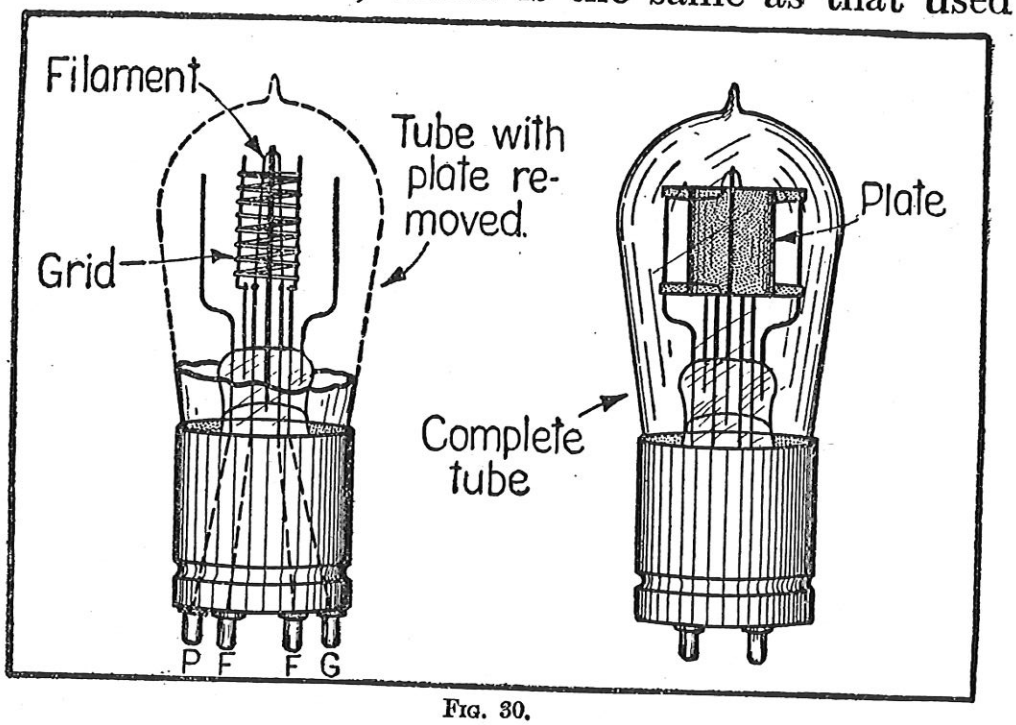

FIG. 30.

in an incandescent lamp; this is heated by means of a battery of from four to six volts. We next have the grid which may be in the form of a grid-iron or a spiral, it making little difference which. Opposite the filament and with the grid in the middle, we find the plate, usually a small piece of nickel or other metal. The connection of the simplest audion is shown in Fig. 31. If we make the plate positive with respect to the filament, we find that highly charged electrical particles called "electrons"

travel constantly from the filament to the cold plate. It was soon found that the vacuum tube acted as a sort of valve for the electrical current, allowing the high frequency currents as they came over the ærial to travel in one direction in a vacuum tube

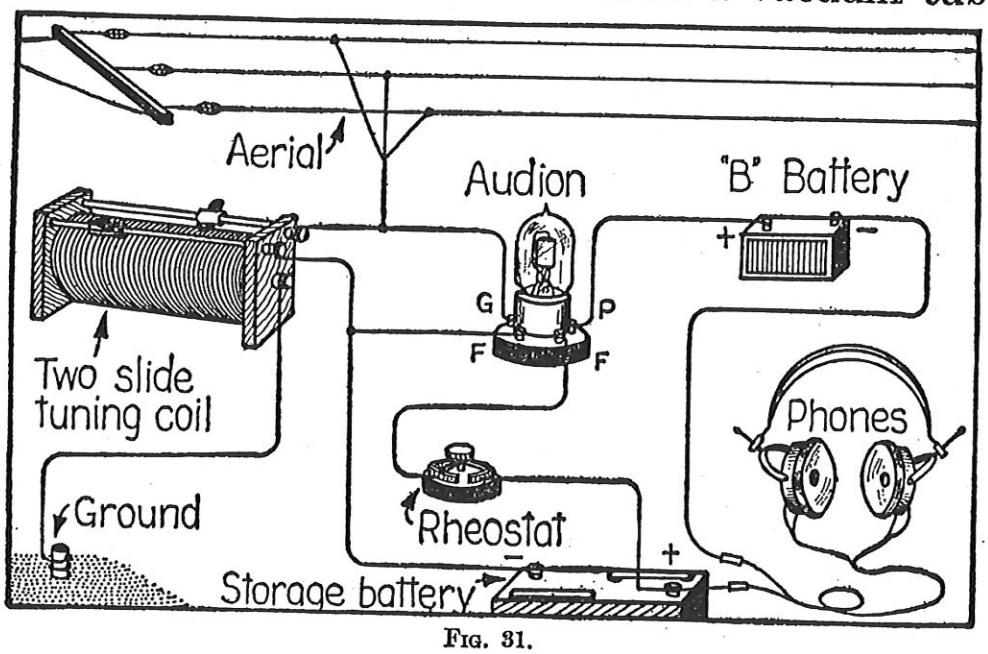

FIG. 31.

but not in the other. In this respect the vacuum tube is the same as a crystal detector, which also acts as a valve, permitting currents to pass one way only.

The vacuum tube was first invented by Dr. Fleming, to whom belongs the honor of using it first as a detector for radio. He was using only a two-element tube, *viz.*, an exhausted bulb containing a filament and a plate. Dr. De Forest conceived the idea of introducing a third electrode into the tube, as explained above. The purpose of this electrode which he called the grid, serves only to control the flow of the electrons at-

tracted by the cold plate. It is the grid that makes the vacuum tube the exceedingly sensitive apparatus that it is. Making the grid alternately positive and then negative varies the amount of current that flows from the hot filament to the plate, decreasing, and even stopping it entirely. The grid simply acts as a gate valve which controls the plate current. The curious thing about the grid is that it uses no great amount of power. A modern vacuum tube is exhausted to a very high degree, because it was found that unless the vacuum was perfect, the sensitivity of the tube was very poor. It is not necessary here to go into a very technical discussion of the vacuum tube, as we are merely interested in its functioning. The study of the vacuum tube, however, is a science in itself today, and for that reason it can only be treated generally here. We must, however, add that the vacuum tube is far more sensitive than other detectors, particularly when used in connection with other vacuum tubes. It was found, for instance, that this was the case when several tubes were coupled together; this gives us the so-called two-step or three-step amplifier, which will be discussed later on. The idea of these amplifiers is for each to step up the exceedingly weak current received from the first tube, usually called the detector tube. By means of such a stepping up process, it is possible to bring in signals over tremendous ranges, a thing impossible to do with any other detector known at this time.

THE WIRELESS EXPERIMENTER'S MANUAL

INCORPORATING

HOW TO CONDUCT A RADIO CLUB

DESCRIBES

PARLIAMENTARY PROCEDURE IN THE FORMATION OF A RADIO CLUB, THE DESIGN OF WIRELESS TRANSMITTING AND RECEIVING APPARATUS, LONG DISTANCE RECEIVING SETS, VACUUM TUBE AMPLIFIERS, RADIO TELEGRAPH AND TELEPHONE SETS, THE TUNING AND CALIBRATION OF TRANSMITTERS AND RECEIVERS, GENERAL RADIO MEASUREMENTS AND MANY OTHER FEATURES

BY

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Instructing Engineer, National Wireless Association
Member Institute of Radio Engineers

Author, "Practical Wireless Telegraphy," "Vacuum Tubes in Wireless Communication," "How to Pass the U. S. Government Wireless License Examinations"

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to the second binding post by means of a flexible piece of cord. The stationary and rotary coils can also be connected in parallel with each other when small inductance values are required.

CRYSTAL HOLDERS.—Experimenters have shown scores of designs, many of them ingenuous and providing very accurate adjustments for sensitiveness. The chief consideration in the design of a crystal holder is to provide means of obtaining a contact with any spot on the crystal. A contact with a variable tension is desirable with most crystals.

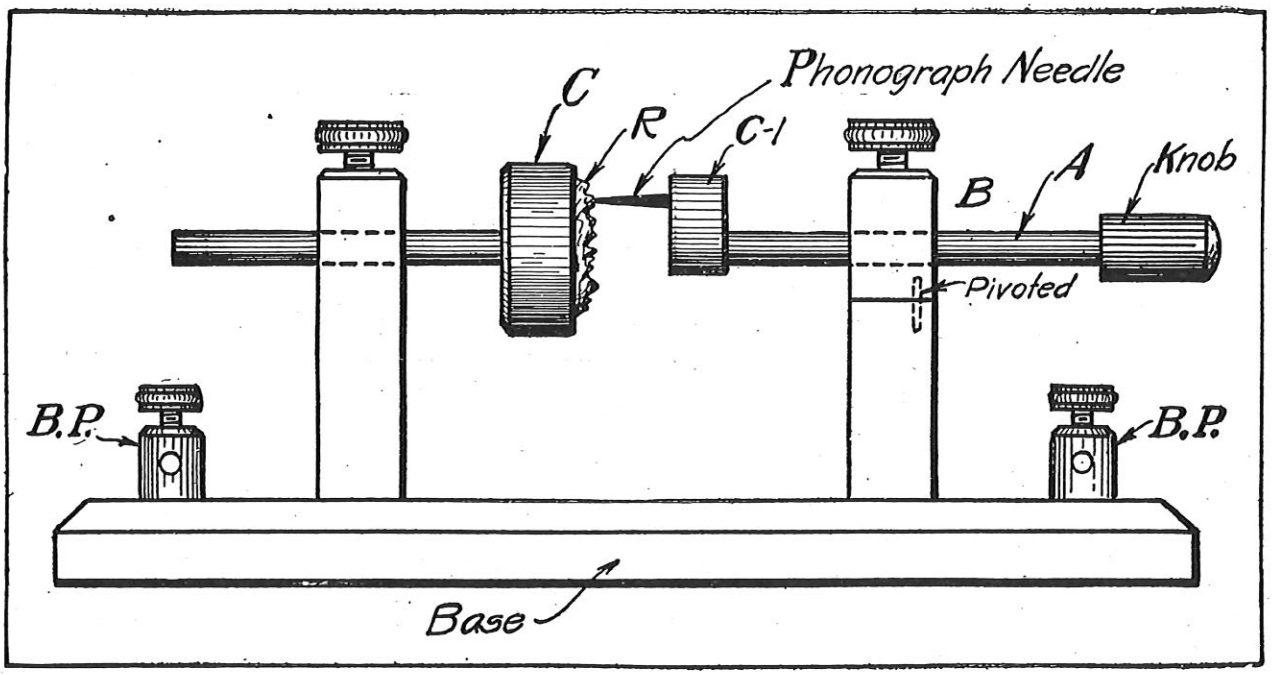

FIG. 151. Detector stand for carborundum crystals.

A detector stand suitable for carborundum crystals is shown in Fig. 151. The crystal *R* is imbedded in a retaining cup *C* by means of *Woods metal* or some other readily fusable compound. The opposing contact is a steel phonograph needle mounted in a cup *C*-1 which is set off center on the arm *A*. The latter has a universal movement, as a sidewise motion is provided by the pivot and a "round and round" movement at the cup *C*-1. A spring tension may be provided for the arm *A* but the details for this are not shown. The sketch of Fig. 151 is drawn approximately to scale.

B. B. Alcorn of New Jersey has shown an excellent design for the use of several crystals of which the details are given in Fig. 152 and are self-explanatory. The dimensions may be varied to suit the builder. The cups for the crystals are mounted on a brass or copper disc $\frac{1}{8}$" thick, fitted with a knurled hard rubber ring for turning the various crystals into position.

The supporting rod and overhanging arm are made of square brass rod. The method of supporting the phosphor bronze contact point deserves particular attention.

Daniel O'Connell of New York City has developed a detector stand of the "cat whisker" type suited particularly to *galena crystals*. The details of construction shown in Fig. 153 are self-explanatory. The crystal is placed in a small glass tube between two "cat whisker" contact points mounted on rods supported by vertical binding posts.

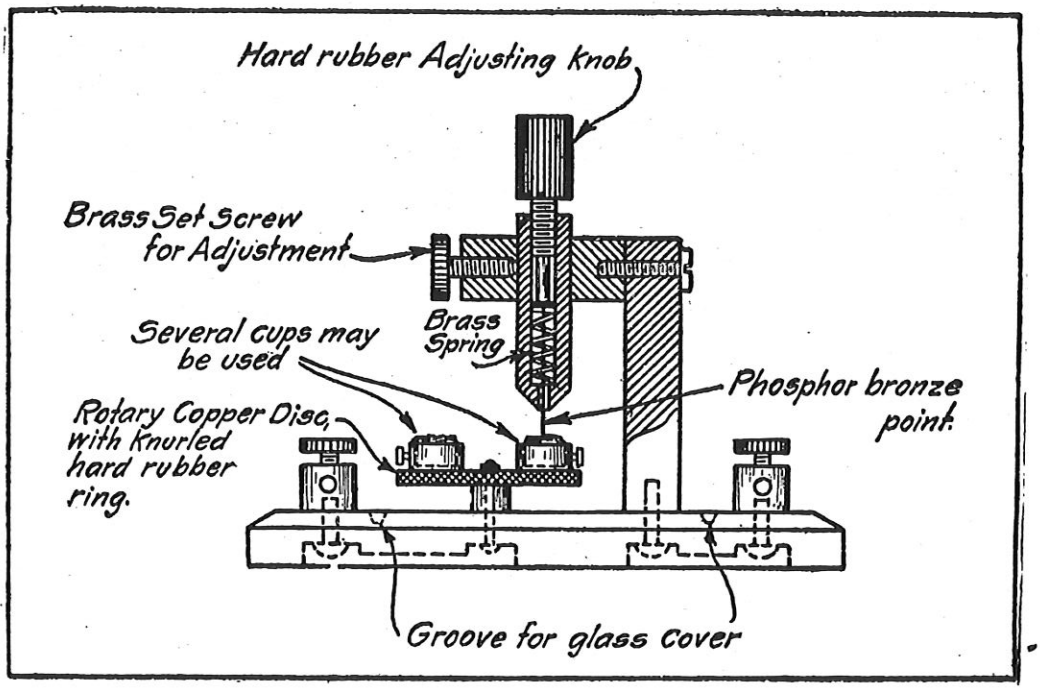
Hard rubber Adjusting knob
Brass Set Screw for Adjustment
Several cups may be used
Brass Spring
Phosphor bronze point
Rotary Copper Disc, with knurled hard rubber ring.
Groove for glass cover

FIG. 152. Detector stand for the use of several crystals.

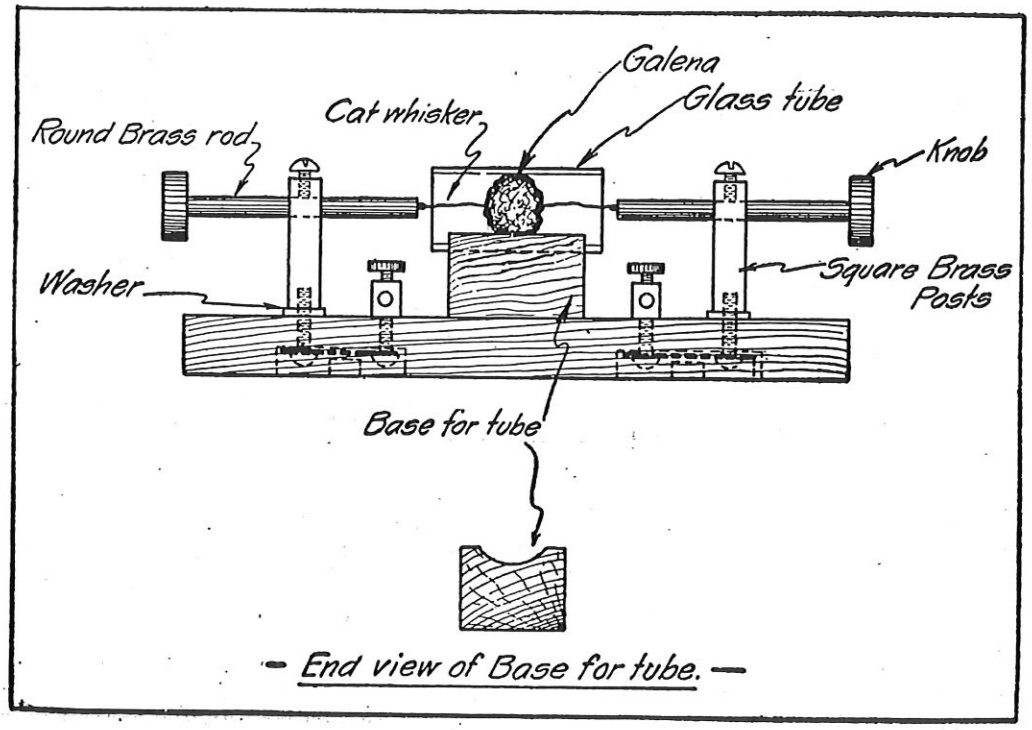

FIG. 153. "Catwhisker" detector stand.

There are several ways of providing an adjustment for this detector. The upright standards may have offset swivel joints on their tops to permit the "whiskers" being moved sidewise; the whiskers may be moved in or out; or the glass tube holding the mineral may be revolved until loud signals are obtained. If the mineral is so small that the tube permits too free a movement, it should be wound with tin foil until it fits the tube snugly.

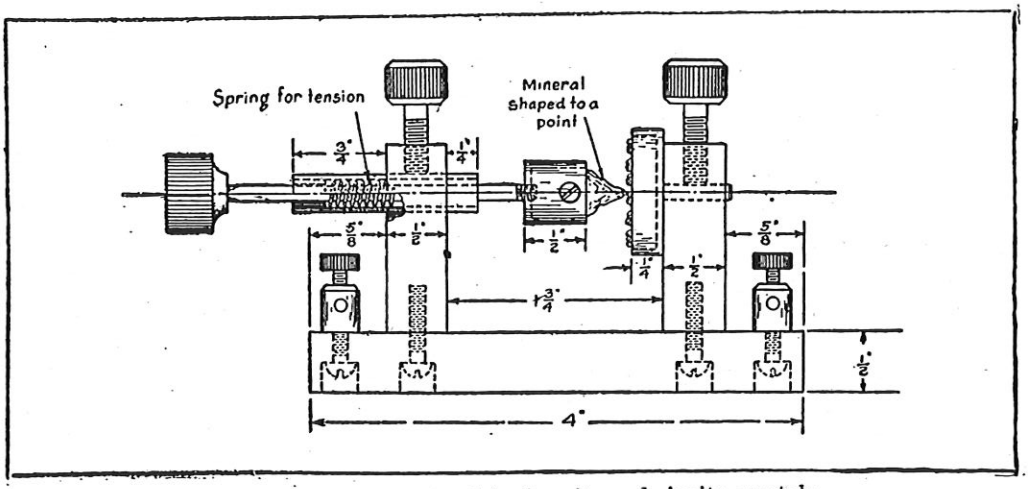

FIG. 154. Detector stand for bornite and zincite crystals.

Fig. 154 shows a detector stand for *zincite and bornite crystals* designed by John E. Finn of New York City. The large cup in which the zincite crystals are imbedded with Woods metal is 1″ in diameter, ¼″ deep. The other cup which is ½″ in diameter and ½″ deep contains a single crystal of *bornite* shaved to a point. The remaining dimensions are given in the drawing.

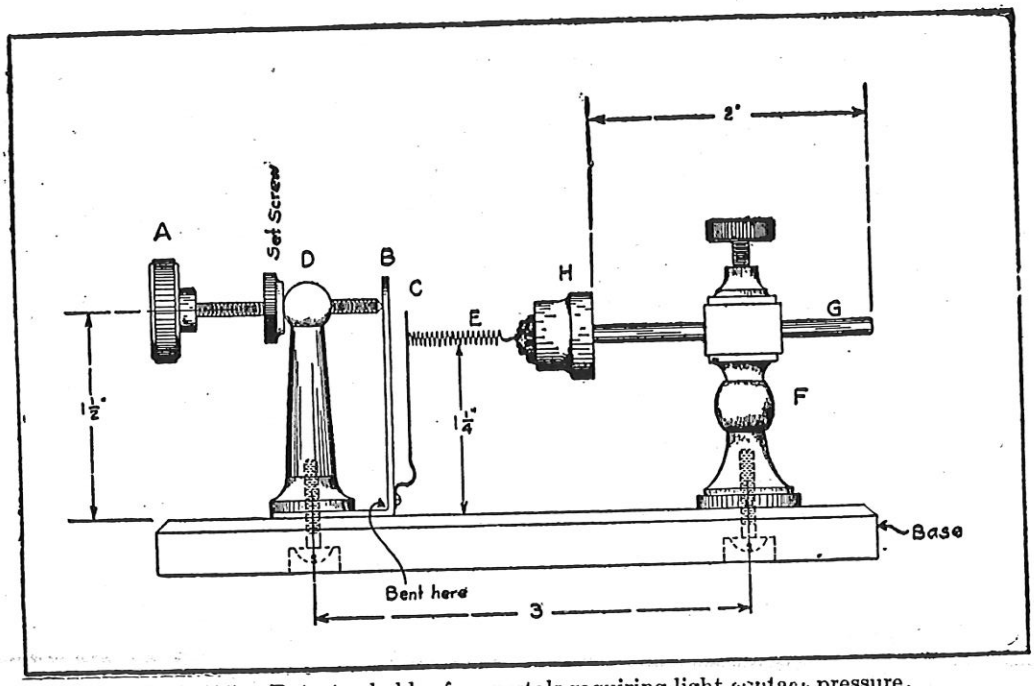

FIG. 155. Detector holder for crystals requiring light contact pressure.

John Shaler of California regards the detector holder of Fig. 155 as particularly suited to crystals requiring light contact pressure. The principal dimensions appear in the drawing. The material for construction can generally be found around the amateur's workshop.

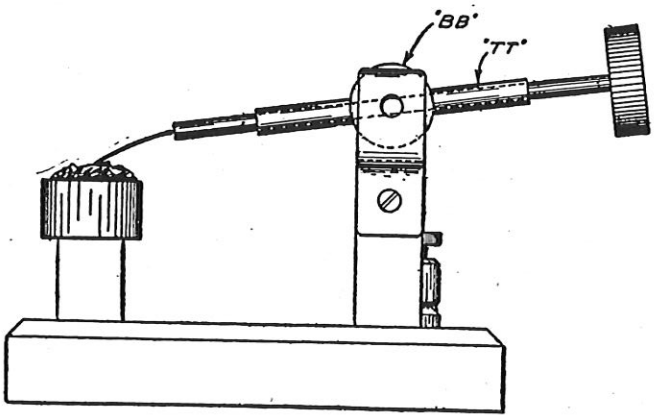

FIG. 156. Detector stand for universal adjustments.

Fig. 156 shows a detector stand the arm of which is fitted with a ball joint to permit contact at points over the entire surface of a galena crystal. It was designed by J. F. Bernard of New York City. *B B* is a brass ball $\frac{5}{8}''$ in diameter, with a $\frac{3}{16}''$ hole bored through the center. *T T* is a brass tube of the correct diameter to slip inside the hole in the ball. The whisker is a No. 30 copper wire. The ball is clamped between two uprights which are of exactly the correct tension to hold it firmly.

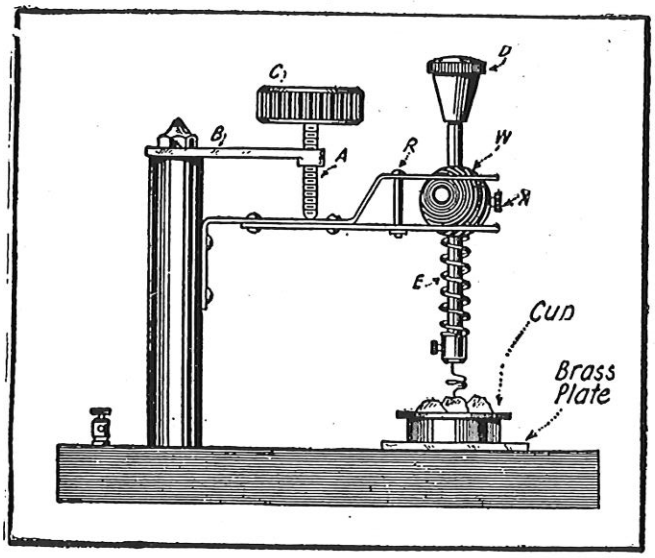

FIG. 157. Detector holder for accurate adjustment of contact pressure.

Another detector holder with a universal ball adjustment, designed by J. G. Stelzer of Michigan, is presented in Fig. 157. Tension is given to the contact point by the spiral spring *E*. Additional tension is provided by the elastic arm supporting the ball joint and contact piece, through the adjusting screw *A* operated by the knob *C*. The finished

instrument should have dimensions about 1½ times those given in the drawing. A universal movement is provided by the ball *W*.

ELECTROLYTIC DETECTOR.—A receiving detector which has rapidly fallen into disuse since the discovery of the sensitive crystals and vacuum tube amplifiers is the *"whisker point" electrolytic responder*, though this played an important part during the early days of wireless telegraphy in the United States. The essential elements of this detector are indicated in Fig. 158.

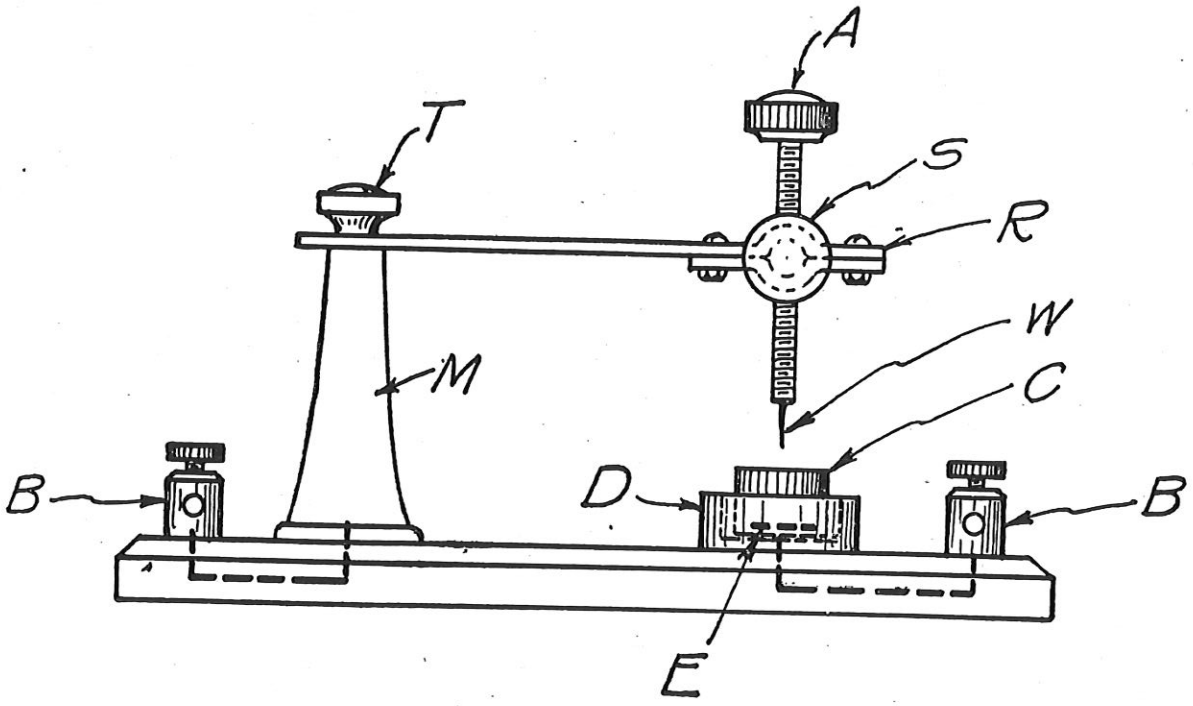

FIG. 158: Fundamental design for the electrolytic detector.

Referring to Fig. 158: The upright binding post, *M*, has the extended arm *R*, through which is screwed rod *A*. This has a piece of platinum wire *W*, with a diameter varying from 0.0001″ to 0.000038″ soldered to the lower end. This wire is known as *"Wollaston wire"* and was formerly used for another purpose. It is coated with silver to permit easy handling.

The fine platinum point dips into the glass cup *C*, which need only be large enough to hold eight or ten drops of a 20% solution of *nitric acid*—the electrolyte. In the base of the glass cup is placed a small sheet of *platinum E*, about 3/16″ square, which is connected to the right hand binding post *B* by means of a connecting wire placed under the hard rubber base.

The circuit for this detector is the same as that used with carborundum rectifiers. The local battery should be one of five or six volts, and should be shunted by a wire-wound potentiometer of 300 to 400 ohms

resistance. The telephones may vary from 75 to 2000 ohms, the important thing is that they be well constructed and sensitive. The positive pole of the local battery should be connected to the fine wire point of the detector.

Two rules must be observed in order to adjust this detector to a sensitive condition. First, the fine wire platinum electrode must just touch the acid, in fact barely make contact with it; second, the silver must be removed from the platinum wire.

The silver coating may be removed by one of three methods: First, an abnormal current from the local battery may be sent through the electrolyte with the platinum point slightly submerged. A hissing, grumbling sound will be heard in the head telephone which, after a period of two or three minutes becomes of less intensity. The current from the local battery should then be reduced until a loud response is obtained in the head telephone from the buzzer tester. If the silver has been thoroughly removed, good signals will be obtained. The second method of removing the silver is to take the platinum wire and place it for a moment in a very strong solution of chemically pure *hydrochloric acid*, the point being removed at intervals and examined by the aid of a magnifying glass to determine the degree to which it has been "trimmed." When an extremely fine "whisker" is observed, the point is ready for use, and it should be dipped in fresh water to prevent further action of the hydrochloric acid. The third method is to heat a small amount of mercury over a Bunsen burner. If the platinum point is dipped into the hot mercury, the silver will immediately be removed.

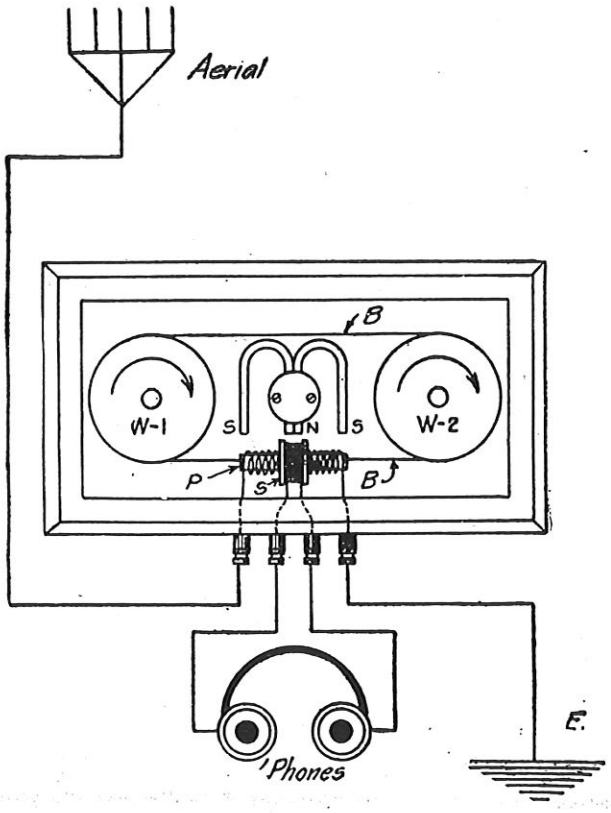

FIG. 159. The Marconi magnetic detector.

The amount of acid in the containing cup and the area of the surface of the lower electrode of the coil are unimportant, except that the upper point and the lower electrode should be separated no more than ¼″.

MARCONI MAGNETIC DETECTOR.—This detector offers some interesting possibilities to experimenters of a scientific turn of mind. Contrary to the belief held by some amateurs, it is rather sensitive particularly at wave lengths around 2500 meters where it will give as good signals as a carborundum detector. The magnetic detector shown in Fig. 159 consists essentially of an iron wire band *B* (several strands of No. 36 insulated iron wire twisted in the form of a cable), with a total length of from 18″ to 24″, which is slowly drawn through the glass tube *P* by the ebonite or wooden pulleys, *W*-1 and *W*-2, which, in turn, are set in rotation by clock work or by a small direct or alternating current motor. The glass tube *P* is wound with from 6 to 10 feet of No. 36 s.s.c. The bobbin *S* is wound with a number of turns of No. 36 s.s.c. wire such as will give it resistance of about 150 ohms. The head telephones joined across the terminals of *S* should have a resistance close to 150 ohms. Immediately above the two bobbins of wire are placed two horseshoe magnets with like poles adjacent. These magnets generally have a spacing between their poles of about 1¼″ and are placed at a distance of approximately ¾″ to 1″ from the band *B*.

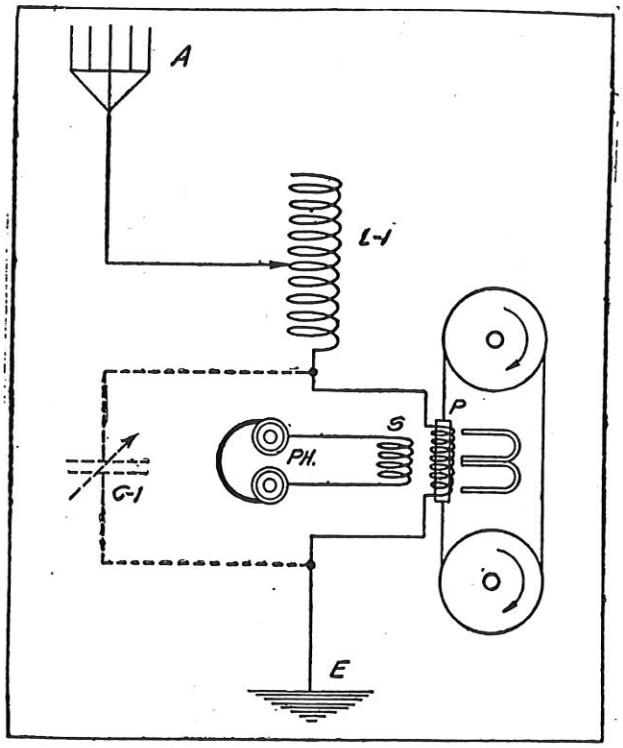

FIG. 160. "Standby" circuits for the Marconi magnetic detector.

The glass tube *P* is usually about 2″ in length and 3/16″ in diameter. The bobbin of wire for the head telephone circuit has a diameter of 1½″ and an overall width of ½″.

When the band *B* is set into movement by the clock-work some parts of it are magnetized as they approach the south pole of the magnet, and

accordingly are demagnetized when approaching the north pole of the magnet; however, the change of flux does not take place on any part of the band as it is directly under a magnetic pole, but is effected at a point beyond, and the final result is that the iron band exhibits marked hysteresis which cause it to be susceptible to changes of magnetic flux when excited by radio frequency currents. When high frequency electrical oscillations flow through the winding P for each group, a momentary change of the flux takes place, which in turn induces a current pulse in the coil S, creating a single sound for each wave train.

The "plain aerial" circuit for the magnetic detector is indicated in Fig. 160, in which an aerial tuning inductance L-1 is joined in series with the primary winding of the detector P. The circuit then continues to the earth connection E. As indicated by the dotted lines a variable condenser C-1 is sometimes connected in shunt to the antenna coil P. With this circuit it is only necessary to tune the antenna to the distant transmitting station, to secure an audible response.

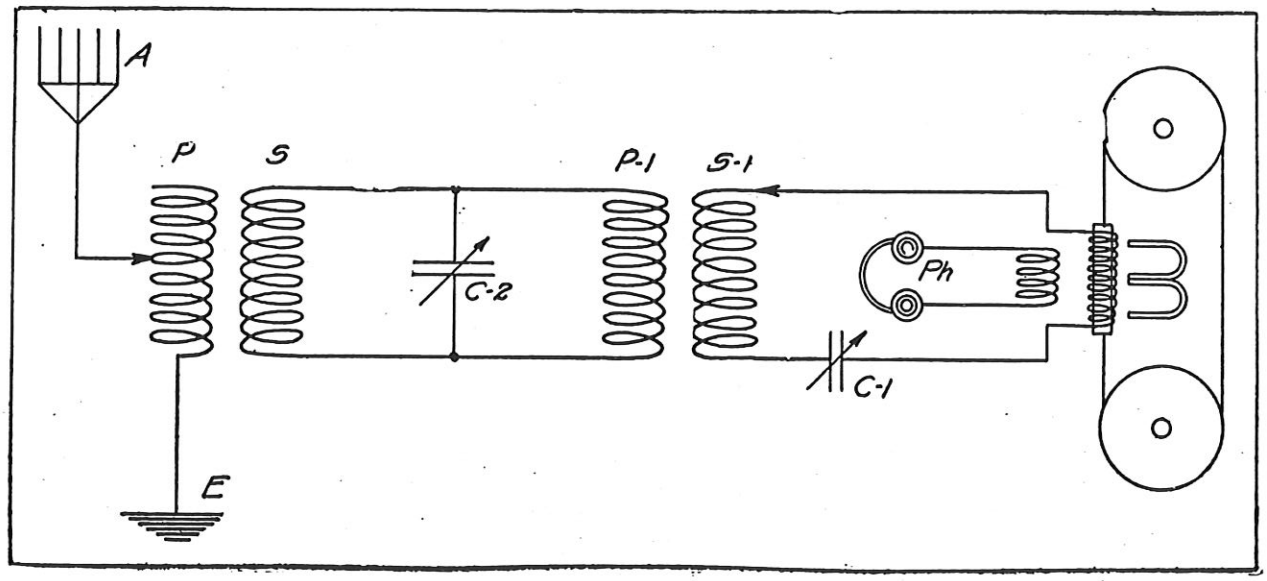

FIG. 161. Circuits of the multiple tuner for use with the Marconi magnetic detector.

For sharper resonance effects the *multiple tuner circuits* shown in Fig. 161 are preferable. The *intermediate* circuit of this tuner comprises the winding S in inductive relation to the primary winding P, the variable condenser in shunt C-2, and the second coil P-1 which is in inductive relation to S-1. The secondary circuit then continues through the variable condenser C-1 to the primary winding of the magnetic detector. Since this detector is a "*current-operated*" device the secondary coil S-1, must have comparatively low values of inductance and resistance. For example, 18 turns of No. 18 bell wire wound on a form 4″ in diameter provide sufficient inductance for waves up to 2600 meters. Litzendraht wire is preferred. In this circuit the variable condenser C-1 is an active part of the oscillatory circuit and the wave length can be changed over a considerable range by variation of its capacity. Usually a condenser of about 0.005 or 0.01 mfd. is employed at this point.